THE STORY OF COPPER

WATSON DAVIS

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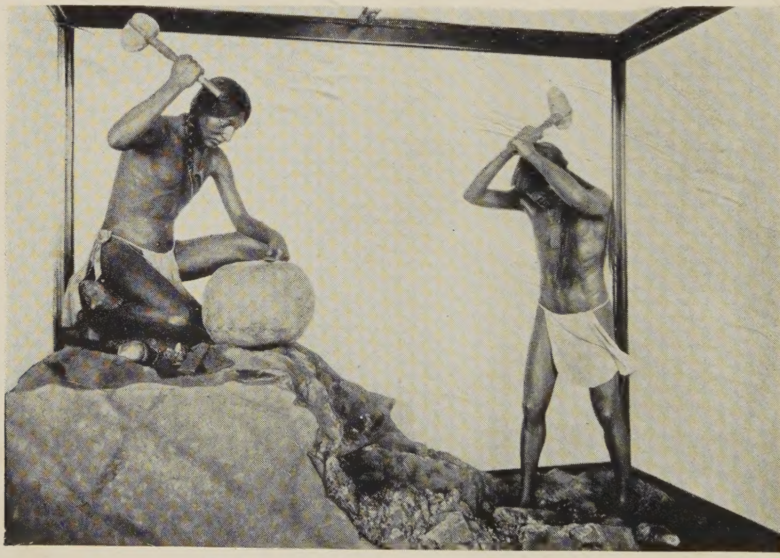
THE STORY OF COPPER

SYMBOLS OF AMERICAN FREEDOM

The Bronze Liberty Bell that announced the Declaration of Independence and the copper Goddess of Liberty, the colossal statue that guards New York Harbor.



FIRST AMERICANS MINING COPPER

Indians were the first copper users on the American continent. This United States National Museum group portrays a warrior, with amulet of hammered copper, completing the extraction of native copper which has been exposed by action of fire and water. A copper knife-blade is being sharpened by blows from the other Indian's flint mallet.

THE STORY OF COPPER

BY

WATSON DAVIS, C. E.

MANAGING EDITOR, SCIENCE SERVICE

ILLUSTRATED WITH
PHOTOGRAPHS AND DIAGRAMS

THE CENTURY CO.

New York and London

Gift - October 1937

PRINTED IN U. S. A.

To

The Man Who First Used Copper

and

The Millions Who Have Improved Upon

His Discovery

This Volume is Dedicated

FOREWORD

Telling the story of a metal so old and yet so modern in its applications has been a fascinating task. My hope is that the printed page will carry over to the reader some of the enduring romance of copper and that every copper-containing object that comes within his view will have a new background.

Necessarily there is little in the following pages that is not more fully told in some frankly technical book. The bulk of the material presented is, like the processes and uses that are described, the common heritage of mankind. As Herbert Hoover says in an introduction to one of his books: "If any may think that there is insufficient reference to previous writers let him endeavor to find to whom the origin of our methods should be credited." I have, however, attempted to include in the reading references the principal sources of more detailed and technical information on copper.

In gathering the material for this book I have had the aid and encouragement of so many people that it would be difficult to thank them all. I am especially grateful to Dr. Edwin E. Slosson, director of Science Service, for his constant advice and criticism and the models of popular science writing that are furnished in his books. I want to acknowledge the coöperation that I have received from Mrs. Davis in the writing

of this book. Without her encouragement, without her collaboration on the portions of the volume that treat of chemistry and art, without her constant aid in checking the information and typing the manuscript, the completion of this book would have been impossible. Among those to whom I am especially grateful for advice, information, and criticism are: Dr. Walter Hough of the Smithsonian Institution, Dr. T. T. Read of the United States Bureau of Mines, Dr. W. F. Meggers, Dr. G. K. Burgess and Dr. H. S. Rawdon of the United States Bureau of Standards, and Captain H. A. C. Jenison of the United States Geological Survey.

WATSON DAVIS.

INTRODUCTION

One who is writing the history of copper does not have to arouse an interest in the subject. He has only to maintain and extend it.

For every one knows copper, however little he may know about it. The first object to attract the infant eye was very likely the brass knob of a bed or door. He early learned the monetary value of the metal by finding that it was legal tender for saccharine delights at the candy-shop or slot-machine.

So also in the childhood of the race was copper the first known of the useful metals. Some savage scientist, unknown to fame, picked up a piece of jagged red rock that seemed more serviceable as a knife than the familiar flake of flint. But when he tried to sharpen the edge with a stone hammer he found that instead of chipping off in little shell-shaped scales, the strange material gave way beneath the hammer-blows without breaking and so could be beaten into any desired form.

We may imagine the pride with which the prehistoric inventor exhibited his new-fangled knife or spear-head to his tribesmen, but we may also surmise that they laughed at him for carrying around such a queer contraption, and that when he demonstrated its superiority over flint he was robbed of his invention by some less original but stronger warrior. For we cannot suppose that troglodyte society was so superior to

ours that an inventor would then meet any better fate than he does nowadays.

Comparatively few people know how beautiful copper is because comparatively few people have ever really seen it. What most have seen is but the painted face of copper, the mask it puts on when exposed to the world. To see the metal as it really is one must strip it of its concealing coat by heating it to redness in a glass tube through which hot hydrogen gas is streaming. Then the copper is revealed as a shining silvery metal, delicately tinted with pink, like the inner petals of a rose, less gaudy than gold, less steely than platinum.

But draw the copper from the closed tube and let a breath of air strike it and instantly a red blush spreads over its face, deepening to a red flush as a baby's skin burns in a seaside sun. This soon darkens to a dull bronze, and further action of the air and moisture gives it a greenish or bluish tint. This fine patina is highly esteemed by artists and antiquarians on roofs and statues, but our municipal authorities call it "verdigris" and scratch it off occasionally with a sand-blast. They had better leave it on for both esthetic and economic reasons, for the bare metal cannot stand exposure, and no paint is more protective than this that is made by the atmospheric agencies against which protection is sought. Coins and castings, coated with the patina, are preserved intact for thousands of years though buried in the damp soil where iron implements would soon vanish in a heap of rust.

The readiness with which copper forms affinities with various elements gave it the name of "the mere-

tricious metal," as the alchemists called it. But this very versatility has its value for human needs, since copper in combination assumes many beautiful and useful forms. The greens and blues of malachite and azurite are gorgeous as any gems, yet they may be had in masses large enough to make table-tops and mantelpieces. Glass and pottery get various hues from traces of copper, and "blue vitriol" is equally familiar to the electrician and to the horticulturist.

Copper is a good mixer. It enlarges its field of usefulness by alliances with other metals. Tin gives it the hardness of bronze. Zinc gives it the golden glitter of brass. With nickel and zinc it makes a passable silver. With aluminum, which man has lately learned to extract from common clay, it forms new and useful alloys. The noble metals, gold and silver, in their proudest capacity as coins and jewelry gain strength by combination with the more plebeian copper.

Copper got its fame from the fairest of the goddesses, who chose it as the metal for her mirror. This was, it must be confessed, "Hobson's choice," for Venus is older than she looks, and when she rose from the sea, somewhere off the island of Cyprus, her first request was for a looking-glass that she might see for herself the reason for the admiration she perceived in all men's eyes. She was not content like Narcissus with the pallid reflection of a pool, which besides could not be carried around with her, and so she sought for a suitable metal. There were only two known at the time, gold and copper. Gold she rejected; not, we must assume, on the ground of expense, for Venus has never lacked admirers eager to

pay for her luxuries, but probably because gold cast a sallow tinge on her countenance, while copper brightened the tint of her auburn locks and endowed her cheeks with a blush like that of modest maidens.

Anyhow the looking-glass of the Cyprian Aphrodite became the symbol of her sex and is still to be found as such ♀ in our modern manuals of botany and zoölogy.

The *cyprium* from the Cyprian isle became the *cuprum* of the Romans and the *copper* of the English, and the metal from which was fashioned the jewelry of goddesses and queens was made into pots and pans and cheapest of coins. A copper button that was proudly worn by a Pharaoh of 4400 B. C. has been found in an Egyptian tomb, but it is not nearly so elegant as the buttons that the elevator-boy lavishly displays on his uniform.

"Not worth a copper," is the nadir of value, yet copper is worth much to the world and never more than now in this Age of Electricity. Light and power are conveyed to our cities and homes by conduits of metallic wires through which flow streams of minute electrons as water flows through pipes. But it makes a great difference in the freedom of the flow what metal is used for the wire. Here copper comes into play, for its conductivity is almost as good as that of silver and much better than iron. A pure copper wire will convey five and three quarters times as much current as an iron wire of the same diameter.

But the copper must be pure. Even the minutest admixture of some other element will impede the electrical current just as a little dirt in a water-pipe

will keep us standing in the cold waiting for the bathtub to fill up. Copper is almost human in its sensitiveness to poisons. Arsenic to the amount of 0.0013 per cent will lower the electrical conductivity of a copper wire by 1 per cent. This infinitesimal amount of arsenic, little more than one part in a hundred thousand, would therefore reduce the range of the telephone wire from a hundred miles to ninety-nine and add correspondingly to the cost of service. So the electricians have demanded of the refiners delivery in thousand-ton lots of copper more free from foreign elements than that which used to pass in the laboratory as "chemically pure."

If the cloud of smoke is to be lifted from our cities, if our factories are to be made clean and our homes convenient, by the substitution of electric power for coal burning, it will be by aid of this humble element. Copper is not so conspicuous as steel yet it is almost as indispensable to the maintenance of modern civilization. It is to increase the popular appreciation of the importance of copper that this book has been written. Here my colleague in Science Service, Mr. Watson Davis, has told "The Story of Copper" in a way to interest those who have no special knowledge of chemistry or concern with metallurgy. Yet I think even those who consider themselves well informed on the subject will find some things new to them as they turn over the pages.

Edwin E. Slosson
Director of Science Service, Washington.

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THE STORY OF COPPER

THE STORY OF COPPER

I

MAN'S BRONZE KEY TO CIVILIZATION

About ten thousand years ago, not so long in the life of humanity, some Neolithic man selected a chunk of reddish "rock" from a crevice in the earth and found that this strange material made a battle mallet that was superior to the stones of his adversaries. He sang the praises of the new "rock" to his tribesmen, and in the secrecy of night, perhaps, his group of stone age warriors quarried and armed themselves with better weapons of a new era.

What amœba could predict man? And what first copper-using tribesman could see, three hundred generations in the future, a modern copper-capped city, sending light, heat, and power through copper, talking and singing over copper, drawing on copper pictures that multiply themselves a thousand times, and using copper coins by the millions?

Probably the news of the new red "stone" and the place that it would be found leaked out in time, through a new age warrior who was careless enough to get captured by the old age enemy. Then the metallic age began in earnest. The Neolithic man became eometallic man, or, to translate the anthropol-

ogist's and my improvised Greek, the man of the late stone age transformed himself into the first man of a new and wonderful age of metals.

How long he continued to call this reddish native metal by the same Neolithic word or grunt that he applied to all the other rocks, no one knows. In fact, we must set our imaginations at work to reconstruct, as we have done, the discovery of copper; six to eight thousand years before the birth of Christ is far too early for any sort of man-written, time-binding record to come down to us.

We can further imagine, synthetically, that there came a time when some early human being, putting a smoother curve on his copper mallet, found that with a hard piece of rock he could laboriously hammer and beat one side of it into an edge that was sharper and deadlier. It became a better weapon. There was a distinct difference between it and the stones of the era past. As the inventor searched his mind for a prehistoric word meaning "malleable stone," he took a step forward.

The place where copper rock was found undoubtedly became a center of commerce, for the new kind of ax was desirable for the ways of peace as well as those of war. Unlike conditions to-day, through the use of the same tool the man of those early times was able to provide his family with meat and other necessities and to protect them as well.

At the first copper-mine, fires were kindled to keep the copper man's family warm, scare away the beasts, and cook the animals that fell under blows from his improved ax.

Perhaps this went on for years; perhaps the reddish rock that could be hammered into axes grew scarce. It was no longer easy to find the hunks of it of the proper size in the rock cracks. Fathers talked of the good old times when copper axes were easy to win from the ground; sons treasured the worn weapons of their great-great-grandfathers. But they still worked in the pits or open mines made by the copper hunting of the past generations, and were rewarded by infrequent finds of the malleable rock. Scarcity of copper rock may have been a subject of grave debate in tribal councils. It probably was a cause of battle when the strong wrested from the weak, but luckier, the better mines that they were working.

We may imagine an economic and martial council around the fire. Inadequate copper is being discussed. One sub-chieftain after another waxes eloquent in urging his particular scheme for relieving the situation. "There are rumors of better, richer mines to the west," says one favoring battle with the happy possessors. "Stone axes were good enough for the fathers of my father," declares a prehistoric, gray-bearded reactionary; but such a suggestion for a return to the old order is laughed down by the progressive younger element that now has to fight the battles. Talk goes on until the dying embers of the pit fire tell them it is late and that it is time to feast on the little dog roasted for the occasion deep beneath the hot bed of embers. The most utilitarian and least favored wife of the entertaining chieftain digs into the pit, which had been constructed from débris of

the copper rock quarry, and begins to remove the glowing coals confined in the hollow.

"Hot!" murmurs a thoughtful chief. "Hotter than the fire that sweeps the forest or opens the mountain!"

"You should have a stick of copper," says another, as the flattened stick-shovel of green wood bursts into flame in the intense heat.

When she has nearly reached the thoroughly baked thick clay case of the deliciously cooked puppy, Mrs. Chieftain can hardly believe her eyes.

"The rocks have turned to fiery water!" she exclaims as she sees a pool of glowing liquid. But as she watches and the others crowd round, the redness fades out.

"We only thought we saw," says one.

"An omen," declares another.

"Perhaps," says the thoughtful one, "we shall see when morning comes."

"Let us feast," invites the host. And what group of weary men, tired of talk, would not?

That night the thoughtful chief dreamed rivers of reddish, fiery liquid sweeping over and annihilating his enemies. Before the sun rose he was raking over the ashes of the festal fire of the night before. No liquid was there. But he found a strange stone, blackened, and shaped like a frozen puddle. He wondered at it, and tried to crack it with a stone quarry sledge. It did not split asunder, but the blow left a dent, a mark that was like that left on the valuable reddish rock of the quarry that was so much desired. Copper? A scratch penetrates the black coating of the

new fire-stone and shows a reddish metallic gleam. "Yes," sneers old gray-beard, when the find was shown to a hastily called council of half-awake chiefs, "I remember, when the malleable stone was not so scarce, we sometimes found ax-size hunks in the ashes of the fire pit into which they had dropped. They were carelessly overlooked in quarrying. With all the care of quarrying to-day, that could happen even now."

Even in twentieth century metallurgy a new method is not achieved in a day. Years may have passed before concentrating "worthless" discards into usable chunks of copper was reliably used by prehistoric man. The dreaming chief and his devotees may have spent their lives proving and improving the first application of fire to the extraction of metals.

It was probably in this manner, complex to them although simple to us, that our ancestors launched the metallurgical age, during which man won hidden metals from unpromising earth and used them as he wished.

After the discovery that metal will melt, it must have been but a short step to casting it. The observant barbarian must have noted that the rough mass of copper took the shape of the hollow in which it solidified; then, perhaps, one day after he had become tired of hammering axes into shape he pondered over tnis. He may have thought the matter out and completed his brain-work by pressing his favorite ax into the earth and forming a mold into which a new ax could be formed. Or this advance in copper metallurgy may have come about by accident as so many things do; into an accidental ax slash in the ground some molten copper may have been spilled, forming an ax blade

that suggested to the improving mind of man a better way to manufacture his tools.

Our story of how the use of metals began is merely a good guess. The human race struggling upward through the stone age and the early part of the age of metals left few traces of their troubles before 1000 B. C. We have only scant Egyptian records, the evidence that is contained in the Scriptures, and incidental references in that source of oldest pre-Confucian history of China, the Shu-King, sometimes described as the "Canon of History." By the time that the fifth to the third centuries, B. C. have been reached, there is a more extensive Greek literature that gives an insight into the metallurgy of that time. During the four to five thousand years from the time when man began to use metal until we have reliable written records,—a space of time about twice as great as the extent of the Christian era,—there is little recorded evidence. We must rely on our deductions from the objects that appear in the remains left by these early peoples.

So vague and mysterious are the beginnings of metallurgy that many of us may be tempted to shirk the task and adopt the explanation of William Pryce, who wrote 150 years ago:

> It is very probable that the nature and use of metals were not revealed to Adam in his state of innocence: the toil and labor necessary to procure and use those implements of the iron age could not be known, till they made part of the curse incurred by his fall; "in the sweat of thy face shalt thou eat bread, till thou return unto the ground; in sorrow shalt thou eat of it all the days of thy life" (Genesis). That they were

very early discovered; however, is manifest from the Mosaick account of Tubal Cain, who was the first instructor of every artificer in Brass and Iron. [''Brass'' of the Bible is not the alloy of copper and zinc, but copper alone. The mistake arose in translation.]

But I think that it will be more accurate and even more interesting to learn what the archæologists and anthropologists have found out about early man's metallic entrance into civilization, even though we have to do a little guessing or accept theirs. It will whet our imaginations, which is not an unpleasant experience.

Perhaps copper was not the first metal to which man introduced himself. In the sands of a river-bed a nugget of yellow may have attracted a man's eye and he may have taken it home and given it to a woman. Gold is a useless metal despite the present-day reverence for it. Even now the gold of our double eagles has to have copper, one part in ten, to reinforce it and prevent it from wearing away. Our first gold was a woman's pretty bauble, probably nothing more.

In the same way, red metal nuggets, worn by water and blackened by air, may have been found by man before the source of the native copper higher up in the mountains was found and exploited for battle-axes. But finds of such alluvial metal were probably mere incidents in pre-metallic times, or they may have furnished occasional better stone-type tools that caused man quickly to recognize and appreciate copper when it was revealed to him in the pit fire or native in the rocks.

When man used fire to loosen the hold of rocks and

elements upon copper, then metallurgy as a useful science came into being.

Copper as a native, free metal, such as has been described in our hypothetical opening scenes of the metal age, did not long satisfy the needs of an improving world. In some manner, it was discovered that a pretty red earth, suggestive in color of copper, actually was in part this metal and that the heat of blown fire would unlock copper from its oxide if this ore was underlaid with charcoal. When this was accomplished it must have been a transmutation far more wonderful in that day than if some miracle-worker of to-day suddenly turned lead into gold for us. Was the first smelting of copper ore consummated in a pit fire that was blown into high heat by the puffed cheeks of an inquisitive experimenter? Perhaps. We know that in some such way the method of building a primitive furnace was puzzled out, and the reward was copper. Once the secret was discovered, crude methods gave way to better ones. Human bellows were supplanted by some mechanical arrangement, such as the fan-like hand blower that is used with the braziers and small cooking fires in many parts of the world, and this in turn gave way to better draft-producing devices.

After this metallurgical method had been tried for a few centuries men probably discovered that all red earth for copper-making was not the same. An ax made from the ore of one mine seemed to be strangely harder than one made either from different red earth or from the native metal. The owner of the harder ax probably rejoiced and remained content in the

possession of a superior weapon. Bearers of inferior axes scratched their heads and looked around for a reason. Eventually a difference in the look of the better ore and ax led man to the realization that he had something new in metals—bronze.

Archæologists differ among themselves, and archæologists and metallurgists disagree widely in their beliefs as to how the first alloy, a combination of copper and tin, was first made. Some believe that it occurred in the way that has been described, by the smelting of a combination of copper and tin oxides mixed together in nature's veins in approximately the right proportions for man's use. Others reconstruct for themselves the picture of separate smeltings of the red earth that gives copper, and the metallic-looking alluvial cassiterite, oxide of tin, found in beds of streams. They see man with these two metals, one of which he does not know well; and they naturally suppose that he tried to mix them and that a serviceable bronze was the eventual result.

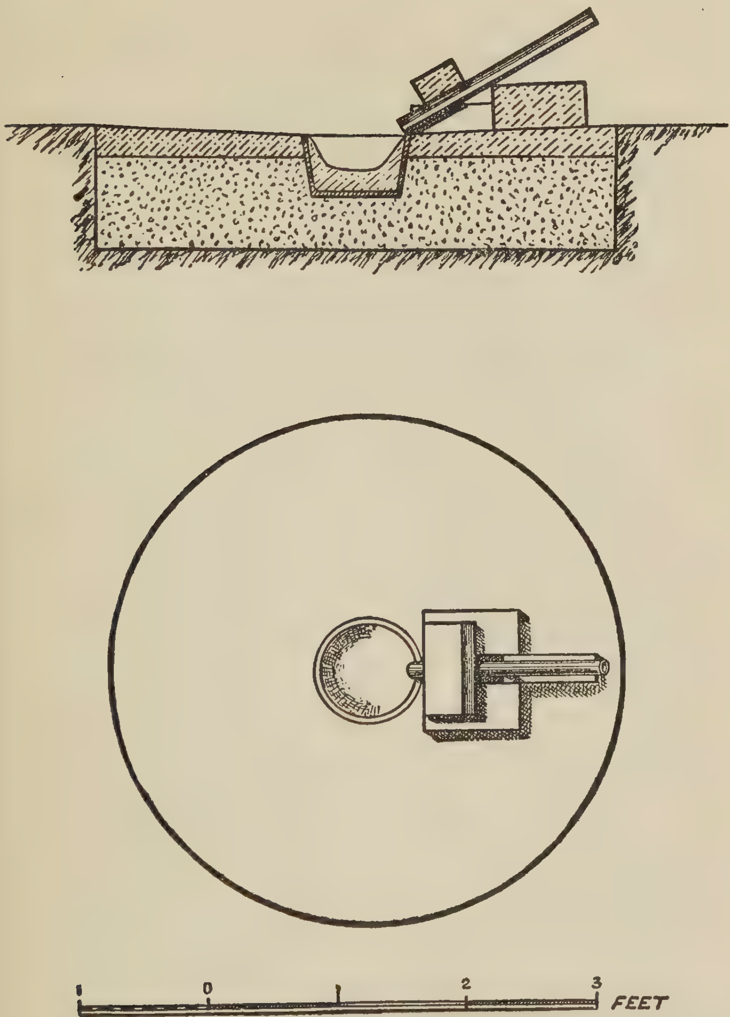
Again, we may imagine a primitive furnace turning oxide ore into copper. Coming in from an expedition, a tribesman, perhaps, showed the furnace-tender a handful of metal-like tin oxide nuggets that he had found among the stream-bed rocks that were used to make the stone implements which copper had not supplanted. They decided to add this material to the copper, and bronze resulted.

All three of these methods of making bronze may have come first in different places, but that brings us to another disputed question, whether there was more than one beginning of the age of metals. We

are fairly sure that in Mexico, before the white men spoiled a growing culture, the Aztecs smelted a natural bronze from a mixture of copper and tin ores. But except for such isolated cases, evidence seems to favor a separate smelting of the ores and alloying the two metals as a third operation.

For our reconstruction of the bronze age furnaces, we have more than our imaginations alone to draw upon. In parts of Europe, many "founder's hoards" or "smelter's hoards" of the bronze age have been found. Their rude round copper cakes, eight to ten inches in diameter, have taken the shape of the bottom of the pits. In Egypt archæologists have found a few pictures of crude furnaces and bellows, which show that as early as 2300 B. C. there had been a considerable advance over the crude hearth. By analyses of early copper tools we learn that little sulphur is present, and we are thus able to say that it was oxide ores, not sulphides, that were first smelted.

Archæologists and anthropologists also use a "back to nature" method of determining the most probable methods of bronze age man. They imagine themselves transported to ancient times; they use the tools of that age, and then, pitting their own skill against that of their ancestors, attempt to do what they must have done under the conditions of their times. This method has been used more than once to help settle controversies. It is still a question, as I have said, whether the copper and tin in old bronze occurred naturally in mixed ores, or whether the two metals were smelted separately and then alloyed. Professor William Gowland was a strong believer in the mixed ore theory, but



A RECONSTRUCTION OF A PRIMITIVE FURNACE AT THE ROYAL SCHOOL OF MINES

In such a hole in the ground Bronze Age man is supposed to have smelted malachite to obtain copper or malachite and tin-stone to obtain bronze

there were others who said that bronze could not be produced in that way, as the tin would go off in the slag. In the floor of the Royal School of Mines, Professor Gowland reconstructed a primitive furnace, such as must have been first made four or five thousand or more years ago, and became a strong-lunged metallurgist in the making. From a mixture of green carbonate and tin-stone, in such a furnace, with charcoal for fuel, he smelted bronze containing twenty-two per cent. of tin that would have pleased the most advanced inhabitant of the bronze age. Many of the American Indian ornaments that date before Columbus's voyage across the Atlantic are such wonderful examples of the coppersmith's and jeweler's arts that some have doubted their early origin. Several archæologists have equipped themselves with wood, stone, and copper Indian tools, foresworn steel and iron, and proved by action that such primitive tools in the hands of a man could have produced designs in copper that are valued to-day as much for their workmanship as their antiquity.

To-day we say "brass and bronze" in the same breath. The two words sound well side by side, and the two materials work and look well together. It is hard to realize that civilizations rose and died between the invention of bronze and the invention of brass. As has been described, bronze came into use at least earlier than 3500 B. C.; brass was not used until shortly before the Christian era. Brass is less than half as old as bronze; a stretch of time a thousand years or more longer than the Christian era separated the initial use of these two important alloys of copper.

There is a reason for this. Brass is much more difficult than bronze to make and cast, and zinc is a metal that likes oxygen much better than does tin, copper's partner in making bronze. When zinc is heated, it burns and changes to a white vapor, zinc oxide, if it is given an opportunity to snatch the necessary oxygen out of the air. While the burning of zinc into oxide is a profitable present-day operation and results in white pigment for paint, it hampered ancient brass-making. However, zinc as a metal was not known to the brass-makers of the time shortly before the Christian era; in fact, it was not until the middle of the sixteenth century A. D. that zinc in its free state was actually used and identified. An earthy substance, the ore calamine, a hydrated zinc silicate, was the material which the metallurgists mixed with copper to form brass that is called *aurichalcum* in early Roman writings. It was not until modern times that spelter, as the metallic zinc of commerce is called, came to be used.

It was Dioscorides who gave in his writings the first description of the method of securing *pompholyx,* zinc oxide, as follows: "The soot flies up when the copper refiners sprinkle powdered *cadmia* over the molten metal." He thus indirectly leaves the first definite indication of making brass. From him also we learn for the first time of copper made from sulphide ores, for though he was writing a medicinal treatise, he states that "pyrite is a stone from which copper is made." How late it was that man became acquainted with the sulphide ores that to-day furnish two thirds of all the copper produced in the world! This same

After Morgan in "L'Humanité Préhistorique"

LOCATION OF THE TIN AND COPPER MINES THAT ARE KNOWN TO HAVE BEEN WORKED BY EARLY MAN

Egyptian figure of the sixth century B.C. typifying the flight of time. Made of bronze.

The four bronze horses at the main entrance of St. Mark's Cathedral, Venice. Originally erected in Rome, sent to Constantinople by Emperor Constantine, they were brought to Venice in 1204.

Brass sanctuary knocker, now adorning the door of Adel Church, Yorkshire, which has served in England since Cromwell's time

The famous Snake Column of Constantinople, exposed to the weather since 479 B.C.. It was originally a votive offering to the Temple of Apollo at Delphi.

Courtesy of the U. S. National Museum

AMERICAN INDIAN IMPLEMENTS AND ORNAMENTS OF PRE-COLUMBIAN DAYS

At the top are barbed spear and arrow points. Within the necklace of copper beads there is a copper bracelet and a small string of beads. To their left are two ornaments, the larger of which is worn on the breast. To the right of the beads there are four knives and a dagger point. The half-moon shaped knives were used by the Indian squaws in preparing food. To the left below the beads is an assortment of projectile points. The large objects to the right of the picture are the blades of hacking implements, called celts, while the slender rod is an awl. The round indented object is an ear ornament. The blade with a depression for a handle, is an implement called a spud, which is somewhat like a modern adz. Most of the implements were unearthed in Wisconsin, but some came from Ohio, West Virginia, Kentucky, Pennsylvania, and New York.

Greek writer also gives us our first description of blue vitriol, the common chemical, copper sulphate, and aptly describes the pieces as "shaped like dice which stick together in bunches like grapes."

That is the story of the discovery and early metallurgy of copper as well as we can tell it to-day. Who took these steps and when they were taken are questions whose answers are quite as vague and quite as interesting. It may be that the use of metals began independently in different parts of the world, but it is equally probable that metallurgy, or the use of fire in working metals, originated from a single nucleus and spread gradually to other parts of the world.

The main part of Africa is the only great world area on which an age using copper or bronze is not recorded. In Asia, Europe, and the two Americas evidences of the use of copper metals are to be found abundantly. But the richest of archæological storehouses are to be found in the parts of eastern Asia Minor, western Europe, and northern Africa that border upon the Mediterranean. In this cradle of culture archæologists have unearthed most of the relics and indications that bring to us the history of prehistoric peoples.

It was in Mesopotamia, perhaps, that man first found copper. His introduction to this first metal may possibly have been through his discovery of native copper in the veins of rock, but more likely he either found usable chunks of it in stream beds or, by some happy chance, learned how to smelt the oxide ores. Again, it may be that Egypt was copper's Garden of Eden

rather than the fertile, sunny country between the Tigris and Euphrates rivers, in which, according to biblical lore, man's origin took place. We do know that after an Egyptian stone age of great skill copper began to be used. In the early Egyptian graves, which serve as the record-books for us to read to-day, there came a time when the weapons and utensils left for the use of the dead were not of stone but of metal. Perhaps this was 5000 B. C.

The stone age and the beginnings of the metal age in Europe, in addition to being of very uncertain date, have only recently and incompletely revealed themselves to archæologists. It is not certain whether the Neolithic pastoral people who left those early remains were the direct ancestors of the later copper-using Egyptians. In many respects the later and more advanced people differed entirely from their predecessors. For three dynasties copper is the only metal that is found in the prehistoric Egyptian remains, but as early as the fourth dynasty bronze articles have been found. This dynasty marked the culmination of the Old Kingdom, and it was a period of wealth and splendor. A passion possessed its monarchs for making monuments to glorify themselves, and it was then that the vast stone piles of the Great and the second and the third pyramids were erected. Depending upon the authorities that are accepted, it was from 3800 to 4700 years before Christ that the kings of this dynasty raised their sepulchral piles. Vain, unmeaning, and wasteful as these pyramids may seem, they are interesting to us because in one of them, that of Medum, has been preserved a rod which

is the oldest piece of bronze that man now knows.

Where the early bronze of Egypt came from is a mystery. We can account for its copper content, because ancient copper-mines, while not found in Egypt, are scattered over those parts of Asia Minor with which the Egyptians had trade relations. Most of the Sinai peninsula, which juts out of Arabia into the north end of the Red Sea, was probably the first source of Egyptian copper. There archæologists have found reliefs dating as early as the reign of the Egyptian king Seneferu, about 3700 B. C., indicating that he worked the copper-mines. The emblem of copper in the hieroglyphics is the crucible, and the finding of crucibles at Sinai indicates that the Egyptians even went so far as to carry on some form of refining.

But assigning an origin to the tin is a different matter. The nearest cassiterite-mines known to the ancient world are either beyond the far end of the Mediterranean in Spain, France, and Britain or clear across the Asiatic continent in China. Within easy reach of Egypt we can find no traces of where the tin could have originated. Archæologists find it hard to believe that as early as 4000 B. C. the Egyptians traded with either western Europe or China, as they must have done if they obtained their supplies of tin from either of these sources. It is true, of course, that the Phenicians, two and a half to three millenniums later, distributed to the ancient world a supply of tin from Spain and Britain; but coupling up this trade activity with the beginnings of the bronze age is like speaking of the recent World War and the fall

of Troy in the same breath. Slender threads point to the yellow East as the source of tin and perhaps the knowledge of metallurgy. A mining engineer's opinion on the origin of Egypt's tin is that it was a home product. Herbert Hoover, who, with Mrs. Hoover, translated Agricola's "De Re Metallica," suggests that alluvial tin may have existed within easy reach and may have become exhausted long before modern man had a chance to see it. How quickly such a source of metal supply can be forgotten, with no evidence remaining, is indicated by the seldom-remembered alluvial gold supply from Ireland. Large tin fields of central Africa were discovered in relatively modern times, and native-made tin ornaments were found in circulation among the negroes there. These facts present the possibility of another tin source near Egypt, and the trade routes into Africa may have been the paths of entrance of the metal into Egypt.

If we knew more of what was happening in China at that time, some of these metallurgical mysteries might be solved. The Chinese worships his ancestors so reverently that archæologists even to-day have great difficulty in searching the burial-places of that great country. Lacking the information that this would give them, they can only surmise what was the state of Eastern progress before about 2500 B. C., when the great pre-Confucian epics of the Shu-King mention the use of copper. Shortly afterward we know that bronze and copper were extensively used. Unlike Egypt, China has her mines of copper and tin side by side, and we do not wonder about the source of these metals for bronze. Bronze vessels of earlier

Chinese times, particularly those of the Shang dynasty from 1766 to 1122 B. C. and the Chow dynasty from 1122 to 255 B. C. are beautiful; often they are inlaid with gold and silver. They are distinctive and have a style of their own, and we may better appreciate these products of the early Chinese culture by reading the poetical prose description of a relatively modern Chinese archæologist writing in 1767:

> Bronze vessels buried in the earth for a thousand years become pure blue, like that of the kingfisher. The color before noon is pale, but after noon takes on the appearance of clouds, and the kingfisher blue seems as if it would liquefy into drops. Bronze vessels subject to the influences of water for a thousand years become pure green, as the rind of a melon, and glossy like jade. If subjected to such influences for a shorter time, although they may be bluish green, yet they are not bright.

In the kingfisher-blue and the melon-rind-green coats of these artifacts we to-day can identify the azurite and the malachite minerals to which a thin film of the copper during a millennium had reverted.

Before the iron-armed Aryans conquered the original inhabitants of India, the northern part of that land had learned to use copper. As early as the late Vedic age, dating from 2000 to 1000 B. C., there are records indicating its extensive use, and from prehistoric times down to the seventeenth century there was a continuous existence of the copper industry. But unlike Europe and the rest of Asia, there was no Indian bronze age; the northern part passed directly from copper to iron. Southern India did not even

have an era when copper was employed, but was still in the stone age when iron-using foreigners came into that country.

From the focus of early origins in Egypt and ancient Asia Minor, Europe probably derived her knowledge of copper and bronze. As early as 3000 B. C., perhaps, metallurgical knowledge had been brought to Crete, and as centuries passed the bronze age crept over the rest of Europe, to Sicily in 2500, to France in 2000, and finally to Britain and Scandinavia in about 1800 B. C. This spread of the use of a metal may not have been a product of the peaceful advance of civilization, but more likely it was carried along with the irruption of an Aryan race into the west and north of Europe. It is entirely possible that in the thousands of years between the time when Mediterranean man discovered copper and when the news and details of his accomplishment found its way northward, some of the north European races had made a few slow, independent starts toward using copper as a metal. About this we can only speculate, but after Egyptian culture had been distributed we know much about how copper and bronze were obtained and used by European peoples.

In the word "copper" we have a living record of the mine that gave the early world a large part of its copper supply. Rome obtained most of its supply of this metal from the island of Cyprus, and for this reason called the metal *æs cyprium,* which was gradually shortened into *cyprium* and corrupted into *cuprum,* from which comes our word "copper," the French *cuivre,* and the German *Kupfer.* As early as 3000 B. C.

this island produced copper according to archæological research, and because of its mineral riches it passed successively under the domination of the Egyptians, Assyrians, Phenicians, Greeks, Persians, and Romans.

The chemical symbol for copper that we use to-day, Cu, is of course the first two letters of the corrupted Latin word. But the graphic symbol for copper that was employed in alchemy can also be traced back to that famous island that furnished an early supply of the metal. Many hundreds of years before Christ there lived at the head of the Persian Gulf a people famed for their wisdom. These Chaldeans, aided by the clearness of their atmosphere, watched the planets and the stars from high places, seeking the relations between the heavens and affairs on earth. The skies played an important part in their lives (they believed so, which amounts to the same thing), and those peoples also linked the heavenly bodies with the gods and goddesses of their mythology. We can hardly realize it now, but in the early mythology, astrology, and alchemy of those days were the beginnings of present-day religion, astronomy, and chemistry. Copper, the useful metal of the ancient world, was important in the three-fold association of metals, planets, and divinities. Venus, the planet, and Venus, the goddess, were symbolized on earth by red metal. Legend has it that Aphrodite, to use the earlier Greek name for the goddess called Venus by the Romans, rose, full-formed, in all her beauty from the ocean's foam on the shore of the island of Cyprus, which christened copper. Thus so firmly associated were copper and Venus, goddess, and Venus, planet, that the alchemists of the

THE CARTOUCHE, OR NAME PLATE, OF TUT-ANKH-AMEN, CONTAINS THE SYMBOL LATER USED TO DESIGNATE COPPER

TWO SLIGHTLY DIFFERENT FORMS IN WHICH THE ANCIENT ALCHEMISTS EMPLOYED THE "ANKH," THE SYMBOL OF ENDURING LIFE, TO DESIGNATE COPPER

middle ages always represented copper by the astrological sign for Venus. This circle with cross attached below was the Egyptian symbol for enduring life. It was called the *ankh,* which will be readily recognized by the newspaper reader of to-day as the middle name of Tut-ankh-Amen, made famous overnight after an oblivion of thirty-five hundred years. The *ankh* may be seen in virtually any collection of Egyptian inscriptions, and among the relics in museums are specimens of the *ankh* in bronze. Since copper is supreme among the common metals in its everlasting qualities, the *ankh* in our thoughts to-day may retain its early Egyptian meaning as well as its later alchemistic symbolism for the metal itself. Those who have seen or studied the charts that the geneticist uses in making the family trees of plants and animals will recognize that the *ankh,* symbol of Venus, goddess of love and enduring life, is used to represent the female while a circle with attached arrow pointing diagonally upward and to the right, the astrological and mythological symbol for Mars and the alchemistic sign for iron, is used to designate the male. What a

train of symbolism and ideas has run through the centuries connecting the material and spiritual portions of early days and the present time!

Throughout France, Spain, and the rest of the Continental area, as well as Britain and Scandinavia, the bronze-using people have left non-corroding traces of their daily life. Founder's hoards, which seem to have been the stock in trade of itinerant founders, have been unearthed in many parts of Europe, and from the worn-out or broken implements, waste castings, and rough lumps of copper and tin that they contain much has been learned. In early centuries the principal bronze products were flat axes, small knives and daggers, and small tools or ornaments, while swords, spears, and shields were unknown. The first metal objects that man produced had the same general shape and use as the stone tools with which he was familiar. After he had used copper and bronze for a time he shaped his weapons and tools so that the superior qualities of metal had a chance to show themselves. When iron came into use the forms of implements made of it were at first copied exactly after those of bronze.

There are some archæologically inclined metallurgists who dispute copper's commonly accepted priority of discovery and believe that iron was isolated equally early and used coincidently. Their arguments do not rest alone on pieces of iron found in Egyptian remains, dating as early as 3700 and 3200 B. C., but they also point out the relative ease with which iron can be won from its ores. Iron is so plentifully scattered over the face of the earth that it seems logical to them that

early man should have first found out how to smelt hematite instead of copper ore. The simplicity of this operation is well exemplified by the present inhabitants of a continent that never had a copper or bronze age, the hill tribes of northern Nigeria, where in native forges the negroes reduce iron sufficient for their needs. Bronze making, except in the few places where mixed ores are available, requires three operations, the smelting of copper and of tin and the mixing of these two metals, while the making of iron can be done in one step. Interesting as this reasoning is, it is true that for a long period during early history only copper and bronze implements seem to have been used. When iron appeared it was received as a substitute, and even for centuries afterward, when iron was the common thing, the veneration of custom and appreciation of copper's qualities caused the plentiful employment of copper and bronze. There is a bare possibility that iron was used coincidently with copper and its alloys and that, because of iron's affection for the oxygen of air and water, iron objects have rusted away in the years that have passed. But despite this doubt, which iron's instability has caused, we can safely set down bronze and copper as the key metals to civilization and culture.

Old World archæology tells the story of early metallurgy as it affects our modern life to the greatest degree, but here on our own home continent, at a date close enough so that we can still have some living contact with it, there arose an independent copper age more interesting and vivid to Americans than similar and earlier progress across the water.

About the time when Mediterranean man was perfecting his Neolithic implements preliminary to a transition into the metallic age, a few human beings in some way wandered across what is now Bering Strait into a new continent that man had not yet trod. It was in this way, so some anthropologists believe, that the beginnings of human life reached America. Thousands of years later Columbus and the succeeding explorers surprised true American cultures that in many respects were as advanced as portions of the white world which they had left behind them. In the early accounts of the first white men who came to the two Americas, and from the remains that Indians have left, we are able to reconstruct a very satisfactory picture of conditions at the time of the discovery, and we are able to look a short distance into the past. Beyond this, America's past is just as nebulous as that of the world before 3000 or 4000 B. C.

The prologue to the first copper-mining in North America was performed during the great ice age several hundred thousands of years ago. The ice-sheet, creeping down from the north, tore many masses of copper from the beds in which they had been deposited by geologic processes and, dragging them southward, spread them over the country and mixed them with débris. The glacier not only mined but transported close to the eventual places of use part of the same deposit of native copper which to-day furnishes a large part of the world's supply. It was the famous Lake Superior deposits that were thus naturally prepared for the use of the North American Indians.

It is probable that the way in which the Indians

came to use copper is the closest actual approach to the imagined story that appears at the beginning of this chapter. Over an area greater than seventy thousand square miles south of Lake Superior nuggets of drift copper had been spread. An Indian, searching for stone suitable for arrow-head making, tried the copper as a substitute material, liked it, and then looked for more. The treasuring of glacially distributed metal led to the discovery that metal was also to be found in crevices of rocks, and undoubtedly it was not long before it was established that a small area near Lake Superior was richest in the metal. This became the center of the greatest industrial achievement of the North American Indian. Until a very recent time the mining pits excavated by the Indians and tens of thousands of stone boulder sledges used by them as mining tools still remained in parts of that region as memorials to aboriginal industry. In some cases such large masses of copper were encountered that the Indians could handle or utilize them only with difficulty. Some of these large chunks of metal were unearthed and moved some distance from the mining pit, only to be abandoned until white men claimed them. The most famous of these, though by no means the largest, is perhaps the Ontonagon boulder that was found on the bank of the Ontonagon River by early explorers. Indian hands had removed this four-ton mass about two miles from the outcrop of the lode which it came from; and in 1843, at the time of the beginning of the modern exploitation of the district, it was removed with much effort to the National Museum at Washington, where it now rests.

Native copper is also found in small quantities in Virginia, North Carolina, Tennessee, Arizona, New Mexico, Alaska, Mexico, and Nova Scotia; and while the natives may have used these deposits, most of their copper came from the Lake Superior workings.

Copper was doubtless treated like stone when the Indians first found it, but finally the malleability of the metal must have caused them to shape their implements by hammering instead of pecking. Copper tools and weapons were first modeled after those of stone, but finally the celts, hatchets, awls, knives, drills, and spear-heads changed in form so as better to utilize the qualities of the metal. The pretty red color of copper and the high polish that they could give it delighted the barbarians' eyes, and the metal had a high value for this reason alone. There is some evidence that a few tribes in North America practised casting to a limited degree, but wonderful results were accomplished by hammering, grinding, and perhaps by annealing. Thin sheets of metal were made by laborious hammering with stone implements, and the highest skill in sheet-copper work is exhibited in intricate repoussé designs found in burial-mounds in Illinois, Ohio, Georgia, and Florida. Even copper-plating was practised by the aborigines. But instead of using electricity to deposit the metal, they covered jaw-bones of wolves, stone, shell, bone, wood, and other objects with thin sheets of copper. We may thank copper for preserving for us some of the rare examples of ancient Indian cloth and other objects that have usually decayed away. When copper beads and ornaments were worn, their salts sometimes impregnated the fibers and

HISTORICAL TABLE OF COPPER'S USE BY MAN

B. C.	*Europe*	*Egypt and Mesopotamia*	*Asia*	*America*
8000—				
		Copper used like malleable stone—metallic age dawns		America probably received beginnings of human habitation from Asia
7000—				
6000—				
		Casting copper discovered; copper reduced from oxide ores by smelting	Did metallurgy come from China?	
5000—				
		Tin reduced from ores and bronze made		
4000—	Man in northern Europe *may* have trod laboriously in early steps taken by southern man			
		3700—Date of oldest piece of bronze yet known, found in Egyptian pyramid		
3000—	Knowledge of copper and bronze spread slowly over Troy, Greece, Sicily, central Europe, France, Spain, Britain. and Scandinavia		2500 — First mention of copper in Chinese literature (Shu-King)	
2000—		Bronze and copper in abundant use	Bronze and copper used in China; northern India in copper age; southern India passed directly from stone to iron age	

	Europe	*Egypt and Mesopotamia*	*Asia*	*America*
1000—		Brass made by cementation of copper and calamine; sulphide ores smelted for copper; blue and green vitriol made		
Christian Era= A. D.				Use of native copper in North America and bronze in South America developed slowly until Columbus and other explorers arrived
1000—				
	1200 — Copper refined by oxidation and poling			
	1550 — Copper ores roasted before smelting			1492 — America discovered

= This small space represents one hundred years; the modern electric age, made possible by copper, occupies only half of this, at the most.

The chronology is only approximate and may be modified by later discoveries. Africa, except Egypt and the northern part, had no copper or bronze age. Even remains of the Neolithic age are hard to find; Africa has been in the iron age since very early times.

poisoned the organic agencies that threaten to disintegrate them.

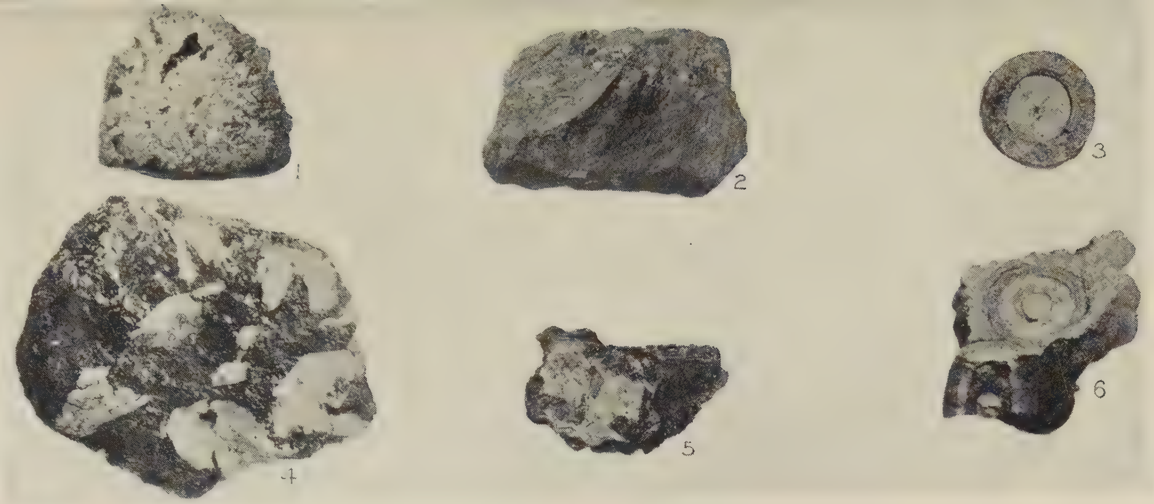
Thus we can see that learning to use metal was a long and sometimes a discouraging process for man. It may have taken a millennium for man to distinguish between stone and copper; in the hundred years just past a wonderfully rapid moving age of invention has remodeled the face of the earth. Man's bronze key to civilization had slowly to unlock the future in different parts of the world at different times; to-day a new development in science is heralded around the world on copper cables, and virtually all of humanity must plunge into a new era together.

CHAPTER II

THE GENESIS OF COPPER

In the beginning, perhaps, all matter was the same. There was no copper. Clouds of stuff, many, many times less dense than our earthly clouds of to-day, floated aimless through universal space, which was and still is cold, lifeless, and void. By processes that our astronomers are only now beginning to understand, nebulæ were converted into giant stars, like Betelgeuze, deep red, larger than our whole solar system but still much less dense than our star, the sun; then after countless eons these became whiter stars, and later they cooled to red again. In some rare cases at some auspicious time a few of these stars unburdened themselves of part of their substance and formed a circling, dependent company of planets. One of these—and, in fact, the only one that we are sure does exist—is the solar system of which our earth is one of the members.

What is copper metal now may have been something else in the beginning. Why we think this was so is another story, which will be told later. After more countless eons one of these revolving planets, our earth, arrived at the point in earthly evolution when some of the elements that had been formed during the ages of stellar evolution were ready to separate



Courtesy of U. S. National Museum

SOME OF THE PRINCIPAL ORES OF COPPER

1. A beautiful example of the dendritic, or fern-like deposition of native copper, against a background of one of its own ores, a dark green malachite.

2. A piece of royal-blue covellite from Butte, Montana. It is a sulphide ore, but is found less frequently than chalcopyrite.

3. and 6. Two banded minerals from Siberia, forms of malachite and azurite. When the markings of these carbonates are as perfect as the ones shown, the minerals often escape the fate of other ores and are cut as gems.

4. A nugget of chalcopyrite, whose color mimics that of gold nearly as effectively as pyrite, the iron sulphide that has earned the name "fool's gold." The white spots are flakes of the quartz with which it is associated.

5. A mixture of malachite and azurite in varying shades of green and blue. The interior of the little cave is pale blue azurite in the form which the mineralogist calls botryoidal, meaning "having the form of a bunch of grapes."

cal analyses of rocks, we see copper in a decidedly subordinate place. It ranks twenty-fourth, sandwiched between lithium and cerium. Above it, and more abundant, we see aluminum, iron, magnesium, chromium, nickel, and other metallic elements. The crust of the earth has larger amounts of all these elements than copper; only two thousandths of 1 per cent. of the crust is copper, or, saying it differently, there would be only one ton of copper in fifty thousand tons of earth's crust if we could assume that all copper were evenly distributed. Yet because nature has placed the total amount of copper in relatively easy form for man's exploitation, there are to-day relatively large amounts of copper available for use.

Now that we know how much copper there is, it is appropriate that we be formally introduced to the copper mineral family, which is responsible for the copper of the world. Some of them we have already met informally in the first chapter, and we shall become intimately acquainted with all of them as our story goes on.

First comes the bachelor of the copper family: native or free copper. It is quite the purest and most solitary member; it is the metal itself. In size, native copper occurs from small grains to great masses several hundred tons in weight, and it may also be found in threads and wires and in distorted crystals and twisted groups. It is not a very hard substance, but the finger nail is too soft to scratch native copper. Native copper is found in twenty-seven States of the Union; in the upper part of copper deposits at the

Coro Coro Mines in Bolivia; the Faroe Islands; Atacama, Chile; and Wallaroo, South Australia; with other deposits elsewhere. But it occurs native in quantity principally in the Lake Superior district, where the Indians worked it long before the white man arrived.

The greatest and most important offshoot of the copper family came about through the intermarriage of sulphur and copper. The sulphur family is rather a troublesome group, and when man divorces these two elements so that he may utilize the copper alone he has more difficulty in performing the separation than he does when copper is married to some milder element such as oxygen. Sulphur, though, does its share in the work of the world, as after the divorce it is often put into service for the manufacture of sulphuric acid.

Next let us become acquainted with covellite, otherwise known as indigo copper. According to its ancestry it is about two thirds copper and one third sulphur. In complexion it is a very dark indigo-blue, and it is considered by many to be the most beautiful of all the copper mineral family. As an ore, however, it is rare, although it is produced in large quantities from one mine at Butte, Montana. In the chemical world covellite is known as cupric sulphide, and the name is written CuS in the abbreviated language of chemists.

The other member of the copper sulphide family is the most important copper ore in America. Its name is chalcocite,—otherwise copper glance and vitreous copper,—and its lineage shows 79.8 per cent. of copper

and 20.2 per cent. of sulphur. Its abbreviated name is Cu_2S. Chalcocite is lead-gray and often has a coat of blue or green tarnish. Often large masses of it have been found, and in the Butte Mine in Montana and the Bonanza Mine, Copper River, Alaska, veins occur whose measurement is more than twenty feet across.

A member of the family that often lives closely associated with chalcocite is bornite. An additional element has contributed to the make-up of bornite, and if we look into its ancestry we find 11.2 per cent. of iron, in addition to 63.3 per cent. of copper and 25.5 per cent. of sulphur, or more simply expressed Cu_5FeS_4. This mineral is also known by several other names: erubescite, purple copper, variegated copper, peacock copper, and horse-flesh copper. It gets these varied names because when first broken open it is of a peculiar red-brown color, which tarnishes to deep blue and purple tints, often variegated. Bornite is an important ore in many mines, notably in some of those at Butte, Montana, in Chile, in South Africa, in Tasmania, and in a few Australian mines.

Another of the family is chalcopyrite, which, judged by its appearance, might be Crœsus himself. It has a true gold color, if you do not happen to see its frequent iridescent tarnish, and it looks genuine enough to fulfil your expectations and yield much gold. But it resembles its cousin, pyrite, or iron sulphide, which has earned the name of "fool's gold," and its color is better called brassy than gold. Instead of gold, chalcopyrite is made up of nearly equal amounts of copper, a baser metal, iron, and sulphur; to be exact, the di-

vision is 34.5 per cent. copper, 30.5 per cent. iron, 35.0 per cent. sulphur. It is also known as copper pyrite and yellow copper ore. This mineral, whose code name is $CuFeS_2$, is often regarded as the mineral from which many other copper minerals are descended; and, in addition to its primary nature, it is geographically the most common copper mineral of the ore deposits of the world, though not the prevailing mineral in the greatest producing mines in this country.

The sulphide branch of the copper family has intermarried with still other elements on the metallic side. When this occurred with arsenic, enargite resulted; and when antimony was the addition, the new mineral was tetrahedrite.

Until a few years ago enargite, known in chemical circles as sulpharsenide of copper, or Cu_3AsS_4, was not considered of great commercial importance, but it has since been found that it is one of the great ores of the world, yielding probably 3 per cent. of the copper. One third of the ore at Butte, Montana, is enargite. This mineral is grayish-black and brittle, and the fact that it contains 19.1 per cent. arsenic caused some persons to scorn it before electrolytic refining provided a method of purifying it. Sometimes, in some kinds of enargite, zinc or iron will be found replacing part of the copper, and the arsenic may have antimony substituted for it in part.

When antimony, sulphur, and copper combine, tetrahedrite, otherwise gray copper ore, is formed. It is a variable mineral, and sometimes we find that the copper is partly replaced by iron, zinc, lead, mercury, or

silver, while arsenic substitutes for antimony. As its nickname implies, it is a light steel-gray to iron-black mineral; and though it is one of the most frequent minerals in copper deposits it is not an important ore, as it seldom occurs in large quantities. Wherever it occurs it usually carries valuable silver along with it.

Next comes the airy branch of the family, formed of a combination of oxygen and copper. The evolution of this branch is usually through a divorce of sulphur from copper with a subsequent marriage of copper to oxygen. Cuprite, Cu_2O, also known by the names of red oxide of copper and ruby copper ore, is usually some shade of red or brown, and it virtually always occurs with the carbonates, malachite and azurite, to whom we shall be introduced shortly. In the early development of copper deposits cuprite was an important mineral because it was at the top of the deposits, but now it has had to relinquish the most important place in production to the sulphide members of the copper family.

The carbonate family, closely related to the oxide branch, is a flashy group, which does a large amount of painting. Most important is malachite, whose color is green; but, occurring close to malachite, the blue mineral azurite will often be found. Malachite, which has the long code of $Cu_2(OH)_2CO_3$ is the most important oxidized ore of copper, and it is not only useful but ornamental. In the Russian mines of the Ural district are obtained large and solid masses from which vases and other works of art are cut. You can buy copper ore in a jewelry store in your city, if you know what to ask for or can pick it out from the

array of semi-precious stones. Many of the brooches and dinner rings containing green stones, often banded with concentric rings, are set with nothing more than the copper ore, malachite. This ore is a little less than two thirds copper, but it often dissipates its strength and color so much that many of the wide-spread deposits cannot be mined on a paying basis. It covers much ground, and a little of it will stain a very large amount of rock. Worst of all, it is deceitful, as it colors thin and worthless incrustations or nodules of worthless material and disguises them as valuable ore. Azurite is malachite's companion, and, like it, is a carbonate, descended, through the union of water, from decomposing members of the sulphide family coming into contact with limestone. Chemically it is known as $Cu_3(OH)_2(CO_3)_2$. The light azure too deep rich blue of azurite contrasts well with malachite's green, and in some localities such as Morenci, Arizona, and Laurium, Greece, nature has been thoughtful enough to form them into concentric bands so that we may easily admire the beautiful comparison. Often it shows off its beauty in splendid crystals, and it is better known for its beauty than for its producing value as an ore.

Chrysocolla is another highly colored ore of copper, and it is the single important representative of the copper silicate family. If we investigate its composition we find 45.2 parts of copper oxide, 34.3 parts of silica, and 20.5 parts of water. Its peculiarity is that it never occurs in crystals, and you may mistake its impure earthy blue and green for a piece of kaolin colored by copper. Often it will be seen with an opal-like

or enamel-like structure. Its most important occurrence is in Arizona, where large areas are underlaid by it, and it is also found in Chile and Belgian Congo.

I shall list the other but minor members of the copper mineral family, mentioning their closest relatives among the important copper minerals. Famatinite is closely related to enargite, the only difference being that famatinite has antimony as a constituent, while enargite has arsenic. Tenorite, better known as melaconite or black oxide of copper, is a member of the oxide family similarly to cuprite, but its code name is CuO, and it is black. It is not very important, although it has the distinction of being formed at the present time by the vapors from the volcano Vesuvius. When blue vitriol or copper sulphate occurs as a mineral it is known as chalcanthite. Like the artificial product it is blue and glassy, and if you tasted it you would find it disagreeably metallic. This is an ore that mine water sometimes leaches out and saves man the trouble of both the mining and the preliminary treatment. Brochantite is another sulphate mineral. Chlorine's intermixture with the copper family has resulted in a basic chloride called atacamite, and in Chile and South Australia, this is an ore of some importance.

It has been estimated that chalcocite and chalcopyrite are together responsible for about three quarters of the world's production; chalcocite probably produces half of the world's copper alone. Native copper, chiefly from the Michigan region, is responsible for about 6 per cent. of the world total and, because of the large masses at Butte, enargite contributes about

3 per cent. The rest of the production comes largely from oxide ores, with the other minerals doing their small bit.

Man is interested in the elements with which copper has intermarried, not only because through science and experience he has discovered that certain ores are usually found under certain conditions, but also because he has to divorce copper from the combining elements before he can use this metal. For the second reason, also, he is interested in the gangue that copper minerals associate themselves with. By the term "gangue" the geologist indicates the rocks and minerals that surround copper ore. These rocks and minerals may be very interesting and, in their proper place, useful, but when they prevent a great density of copper population they are gangue and nothing more. Some kinds of gangues are less troublesome than others, and if they are present in the proper proportion with the proper members of the copper mineral family they may even aid in the process of getting rid of themselves. Quartz, the common mineral, is the commonest gangue of copper ores. Calcite, the carbonate of lime, and siderite, the carbonate of iron, are also common in some deposits but are plentiful in only a few of the greatest mines of the world. Very often the gangue is not composed of these relatively pure minerals but is earthy and a highly altered country rock. Barite, rhodochrosite, and fluorite are other troublesome neighbors of copper ore that man must remove before copper can be obtained.

Pyrite, or iron sulphide, is also a common companion of copper minerals, particularly the sulphides, but, as

we shall see later, it often provides fuel that results in the divorce of copper and sulphur. Iron oxide, or hematite, and other metallic oxides also often form the gangue of copper minerals.

There are some metallic minerals that are deleterious in copper ores, although if they were alone they would be prized as a source of other metals. Zinc and copper do not get along very well in mineral form, although after they achieve the metallic state they often form a successful partnership under the name of brass. Sphalerite, zinc sulphide, is considered the most obnoxious of such harmful minerals, and to discourage it smelters have established a "zinc penalty" which takes the form of a fine if the sphalerite in copper ore is over 10 per cent. Bismuth, arsenic, antimony, tellurium, and selenium minerals are very objectionable associates of copper ores, but electrolytic refining of copper eliminates them and the trouble they cause.

The past history of the copper ores is nearly as mixed and difficult to untangle as human genealogies. So many things have happened in the geologic ages of the earth to complicate the lineage of even one particular spot rich in copper that it often takes years for geologists to find to their satisfaction the probable descent. Each kind of copper deposit has characteristics all its own, and though the types of copper deposits have not been separated very distinctly, their genesis is probably better known than that of the different races of the human kind. Complicated and uncertain as the past of copper may be, it is useful to make an attempt at unraveling it, because through

knowing its past, man can better determine the present location of copper.

Gaze at the ocean, visit a volcano, or admire a hot spring. If you do, it is likely that you are unknowingly witnessing the most recent creation of copper deposits. Sad to say, these new communities of cop per deposits, while "nouveau," are not "riche," and no great exploitable deposits are being formed in this way. Copper salts and copper oxide are deposited by volcanic vapors and gases in the rifts about active volcanoes. Several vein-forming hot springs are known, and one in which copper minerals are being deposited is at Boulder Hot Springs, Montana. Sometimes cold copper-bearing waters are found, but these can usually be traced to oxidizing ore deposits. Copper minerals deposited in the organic muds of sea lagoons, while well-known, are a scientific curiosity rather than examples of how the workable ores used to-day were laid down. Nature at work to-day concentrating copper gives us a chance to see a small part of the geological drama that resulted in the ore deposits that man now works.

If we trace back the genealogy of all the copper deposits of the world, even those that are being formed to-day, we shall find that they originated in the hot, molten material in the interior of the earth. First it was the magma itself, as this molten material of the earth is called, that carried the copper up to the crust of the earth; and when the magma consolidated and intruded itself into the rocks of the crust, the copper as such or in chemical combination, either stayed with it diffused throughout the mass or in a few cases con-

veniently separated itself out. The cooling and crystallizing rocks gave off aqueous solutions that also carried copper upward to be deposited in cracks, and when things cooled down a bit boiling water, emanating from deep molten material, took up the work of transporting the copper to the zone where man can use it. Finally hot springs, just as they are doing now, deposited copper from their waters, which in many cases were a mixture of water from the magma and that which had fallen as rain from the atmosphere and seeped down into the heated regions.

Nature's action in forming ore deposits is only the first step in a process of concentration which man takes up and carries to completion when he mines, smelts, and refines the naturally concentrated copper minerals called ore. But nature has often tried many methods of enriching a single ore deposit as the geologic eras have passed by, and for that reason a description of her concentrating process is harder to write than an explanation of man's more modern and more logical methods.

If copper can be separated from the original molten material or magma, that would seem to be the easiest method of forming copper ore. This has happened, but rarely have workable deposits been formed by this method. The molten magma is composed of various compounds, among them the sulphides of copper and iron, pyrite, pyrrhotite, and chalcopyrite. These metallic minerals need more heat to remain molten than the other parts of the molten rock, and when the cooling process starts, they are the first to become solid. Sometimes the particles that solidify first come to-

gether in masses that become workable ore. Another theory explaining how copper minerals are deposited from the molten magma is that it is due to the fact that the sulphur loves copper better than any other metal. Sulphurous gases escaping through the still molten rock choose copper and change it into its sulphide. These copper minerals concentrate themselves along the contact of the magma with the surrounding rock. It was in this way, geologists believe, that the deposits at Sudbury, Ontario, the only workable American deposits of magmatic origin, were formed.

By far the largest part of the copper in the world is carried upward and laid down in rock by the processes that the geologist has disguised under the terms of "contact metamorphism" and replacement or by ancient processes corresponding to the present-day deposits by hot springs.

The great and valuable deposits of Clifton-Morenci, Bingham Cañon, and Bisbee in this country, and those of the Kristiania region in Norway are classed by geologists under the heading of contact metamorphism deposits. Here is the story of the genesis of these great copper deposits as they tell it. A mass of molten, igneous rock, part lime-soda feldspar and part potash feldspar, pushed its way up into limestones and shales. The gases and solutions given off by the cooling and crystallization of this magma, together with the heat of the molten rock itself, changed the limestones to a compact, impervious rock. It created and left behind garnets and other minerals that the geologist has learned to use as a sign of these changes in the structure of the rock which are called metamor-

phism. Pyrite, rich in copper, was also deposited. As the molten intruding rock cooled down, it fractured, sheeted, and crackled because of the cooling stresses, or possibly there were earth movements caused by the volcanic action. The cracks and fractures allowed more of the gases and solutions from the lower molten rock to deposit their burden of metallic compounds in the breaks of limestone and in the shale, and in some cases the solutions penetrated parts of the now cold and solid upper magma and filled it with mineral.

Such copper storehouses as that at Butte, Montana, are believed to have had their veins filled by a later phase of the igneous activity. When molten rock itself and its gases no longer rose from the interior, hot waters took up the task of elevating copper to near the surface. In part the water probably came from the interior of the earth, but some of the rain falling on the surface above must have seeped down into the depths of the earth, bringing with it some of the copper and other minerals carried up by the gases and the magma as a part of earlier ore depositing activity. These mixed waters were promptly sent upward, and, from the appearance of the deposits at different levels, geologists have guessed how and when they relieved themselves of their burdens of copper compounds. In the deeper parts of the earth the waters were under great pressures that allowed them to take into solution compounds that we usually call difficultly soluble in water. As the upward movement progressed the pressure decreased and the waters could no longer hold the difficultly dissolved compounds. They dropped them, and an ore deposit of that particular

material was formed. This process of gradually getting rid of their metallic burdens continued as the pressure decreased and the waters increased their proximity to the surface of the ground. When at last daylight was reached, the waters had been able to hold on to only the easily soluble substances, such as the alkaline carbonates and the chlorides and silica. Below in veins the valuable copper sulphides had been safely deposited for man to draw upon.

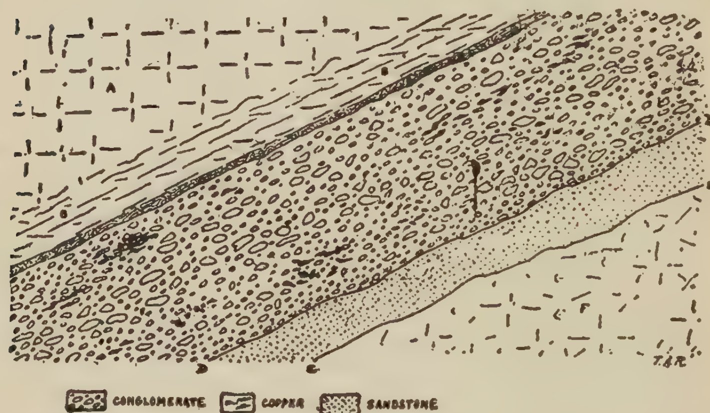
The native copper deposits of the Lake Superior region are also believed to be the result of some phase of igneous activity. In this case, because of unusual conditions, chemical and physical, copper was deposited directly as native copper rather than as an ore.

The famous Calumet and Hecla and Tamarack mines work the beds where the copper was placed in conglomerate as small particles in the cement between the pebbles, and one third of the Michigan copper is obtained from this type of bed. A dozen big mines work the amygdaloid copper-bearing beds. "Amygdaloid" means "almond-shaped," and the beds get this name because the copper occurs in the blow-holes of this form that were left by steam during the cooling of the lava. With the copper, native silver is also found in small quantities. Early in the history of the Lake Superior copper-mines, veins that are now of little economic importance produced most of the copper. In these cracks, formed by filling with copper, or by copper replacing some other elements and taking its form, the famous masses of native copper weighing up to five hundred tons were found.

Whether copper has been laid down in the sediments

of seas is another question regarding copper's genealogy that geologists are attempting to answer. They are trying to decide whether such deposits as occur at Mansfeld, Germany, in sedimentary rocks were created in the same way as the surrounding rocks or whether they had a different origin.

Nature is not usually so thoughtful and generous as

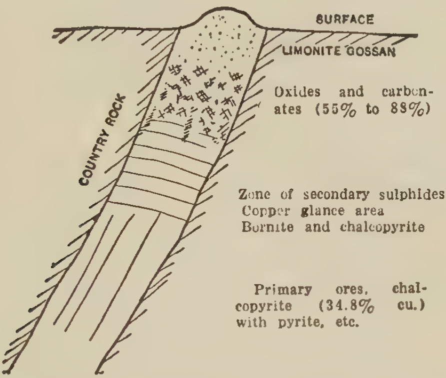


After T. A. Rickard

DIAGRAM SHOWING HOW NATIVE COPPER OCCURS IN CONGLOMERATE LODES IN MICHIGAN DEPOSITS

in the case of the Michigan native copper deposits, where the copper itself attracted men's attention. Often she hides her wealth of copper under a cap of worthless, rusty material. But even when this happens, nature, in endeavoring to bury her copper, has enriched the lower ores and made them more acceptable for man's use. At Butte, Montana; Rio Tinto, Spain; Ducktown, Tennessee; and Clifton, Arizona, this natural concentration of the deposit has occurred

through the action of the weather on the ores near the surface. The primary ores such as pyrite, pyrrhotite, and chalcopyrite are changed by the oxygen of the air and rain-water; and when much iron sulphide is present, soluble copper and iron sulphates result. The descending water carries these compounds to the unaffected ore just below, and there they are precipitated



From Weed's "Copper Mines of the World"

DIAGRAM SHOWING HOW NATURE HIDES A WEALTH OF CONCENTRATED COPPER ORES UNDER A LEAN CAPPING OF WORTHLESS IRON ORE

out of solution. This creates a zone of very rich ore between the worthless, leached-out "gossan" or iron cap, as it is called, and the unchanged original ore further down. In some deposits the lower part of the weathered zone often shows a wealth of so-called oxidized ores of copper. These enriched areas are also due to the downward percolating waters that have stolen the riches of the upper part of the vein. At Butte it was only the silver in the gossan that attracted

the miners and caused them to reach the rich copper glance ore. Many veins in the oxidized zone did not show even a copper stain to indicate that rich secondary ore lay just below.

How long have the various copper minerals been where man has found them? Most of the copper deposits of the world are comparatively young, as geologic ages go. Though, as we have heard before, all copper came from the molten material that formed the earth, it was not until the evolution of life on this earth had been in operation hundreds of thousands of years that the large producing copper deposits of the United States were formed. The age of fishes had passed, and birds, mammals, hard wood trees, and palms had appeared before the creation of the deposits that now provide four fifths of the copper of this country. During the geologic time known as "Tertiary" the great copper deposits of Butte, Montana; Morenci, Arizona; Santa Rita, New Mexico; Bingham, Frisco, and Tintic, Utah; and other places were formed. Although the end of the Tertiary period marks the first appearance of man in the earth's activity and despite the fact that it is a remote date from the point of view of human evolution, it is a very recent date in the history of the formation of the crust of the earth. With the beginning of the Tertiary period an epoch of igneous activity was begun in America which has continued, with occasional interruptions, from that time to the present. Because copper's original source is the igneous material flowing out from the center of the earth, the copper deposits are largely to be found associated with the great

mountain ranges of to-day that were produced by this recent igneous activity. Otherwise copper is found in the old or planed-down ranges where stumps of mountains alone remain. A little older than the Tertiary deposits are those at Shasta County, California; Foot-hills belt, California; Ely, Nevada; Yerington, Nevada; Alaska; Bisbee, Globe, and Ray, Arizona; and others which occurred in the Mesozoic era. These mines in 1913 contributed about 36 per cent. of the copper produced in the United States. But there are copper deposits that can claim a genesis before that of life on the earth. Those of Michigan; Jerome, Arizona; and Encampment, Wyoming, are credited with creation in Pre-Cambrian times. The Ducktown, Tennessee, and other Appalachian deposits, however, date from the Paleozoic era and therefore antedate all the other American deposits except those of the Pre-Cambrian. Geologists guess that Pre-Cambrian times were at least two hundred and fifty million years ago, but that they may have been as much as a billion years in the past.

I am now going to give you copper's secret signs, which can be answered by only the copper family. With them you will be able to tell whether a mineral claiming to have copper in its veins is telling the truth; you will be able to expose any impostors claiming copper's rights.

Submit a copper compound to the test of fire by placing it in a flame, and it will respond by giving the flame an emerald-green to azure-blue coloration, depending on the compound. If a bead of borax is made and dipped into a copper compound, the bead will be

colored green when in a hot oxidizing blow-pipe flame and blue when it cools. When a copper salt is in solution, if ammonia is added, a characteristic blue coloration is produced. Another sign that copper will answer even though only one part in 500,000 parts of water is present consists of adding potassium ferrocyanide to a copper solution and obtaining a brown color, or precipitate.

CHAPTER III

THE EARTH'S HERITAGE OF COPPER

If some one asked you, "How much copper does the earth contain?" you might remember the figures in the last chapter and be tempted to multiply the weight of the earth by .00002 and obtain some 120,000,000,000-000,000 tons as the astonishing answer. But this would be unprofitable meaningless labor, as man has a chance of extracting from the earth and turning to his use only a very small part of the copper in the crust of the earth, and he does not know there is any deeper down.

Before we find out how much copper the world has to spend, let us see how much has been taken from the earth and used. For thousands of years the copper resources of the world have been exploited, but in the last half-century, particularly the last two decades, since demand for copper for use in the electrical and other modern industries has been great, the production has surpassed all previous amounts many times.

More than a million metric tons a year, or over 2,200,000,000 pounds, is the average amount of copper claimed from the earth during the ten years ending with 1920. The United States is responsible for a little less than two thirds of this production, and at no time has even its closest rival produced more than a tenth


ARCTIC OCEAN
GREENLAND
ASIA
NORTH AMERICA
SUPERIOR 6%
SUDBURY
BUTTE 13%
3%
BINGHAM 7%
19% ARIZONA
3%
3%
DUCKTOWN
NORTH ATLANTIC OCEAN
NORTH PACIFIC OCEAN
HAWAII
SOUTH AMERICA
3%
CHUQUICAMATA
SOUTH PACIFIC OCEAN
NEW ZEALAND

WORLD PRODUCTION OF COPPER

EXPLANATION

A SMALL DOT REPRESENTS ONE PERCENT OR LESS OF THE WORLD'S PRODUCTION IN 1913.
MORE PRODUCTIVE LOCALITIES ARE INDICATED BY LARGER DOTS, WITH FIGURES GIVEN WHICH SHOW THE PERCENTAGE OF THE WORLD'S TOTAL PRODUCED AT THAT PLACE.

of the copper of the world. Chile, Japan, and Mexico have at various times during the last decade been the second largest producing countries.

There are given below the figures of the United States Geological Survey for world production in 1913,

WORLD'S PRODUCTION OF COPPER IN METRIC TONS

Country	1913	1918
Austria-Hungary	4,100 [1]	......
England	428	182
France	......	1,228
Germany	49,400	35,000 [1]
Italy	2,091	1,139
Norway	2,741	2,856
Portugal	5,800 [1]	4,000 [1]
Russia	33,694	4,999 [1]
Serbia	6,400 [1]	......
Spain	31,248	45,104
Sweden	4,215	2,956
Turkey	500	......
Total Europe	140,617	97,464
Canada	34,916	53,873
Cuba	3,400 [1]	13,300 [1]
Mexico	52,800 [1]	70,223
United States	555,422	865,705
Total North America	646,538	1,003,101
Argentina	100 [1]	......
Bolivia	900	8,422
Chile	42,263	115,000 [1]
Peru	27,776	44,414
Venezuela	720 [1]	2,079
Total South America	71,759	169,915
Belgian Kongo	7,530 [1]	20,238
Namaqualand	2,500 [1]	......
Southern Rhodesia	......	2,952
Union of South Africa	8,318	4,824
Total Africa	18,348	28,014
Japan	66,501	90,341
Australia	45,647	39,315
Grand Total	989,410	1,428,150

(One metric ton equals 2204.6 pounds)

[1] Unofficial figures.

the pre-war normal year, and in 1918, which is the year when the climax of war production came.

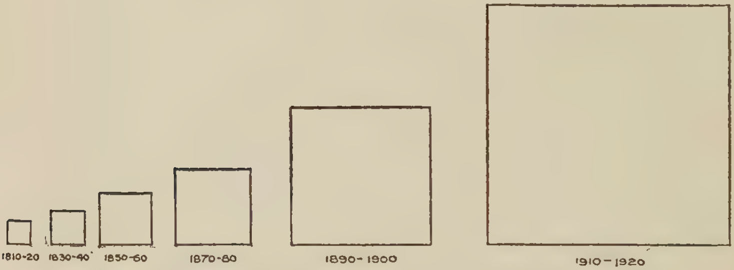
But 1918's record production did not extend over into the next four years. Large stocks of copper accumulated as soon as the war ended, and by 1920 world production dropped to about 834,700 metric tons, less than the total in 1913. Of this amount the United States produced 548,426 metric tons. The figures for 1921 are even smaller, as the production in the United States was only 229,332 metric tons for the year. The year 1922 saw a revival to 432,800 tons, while the production for 1923, 671,400 metric tons, exceeded the production for 1913.

Just how much copper has been freed from earthy bondage since that early day when the first native copper was used can hardly be estimated. Even at the beginning of the eighteenth century the world's production of copper was probably not more than seven thousand tons a year, with Great Britain producing three quarters of this. One hundred years ago the mines of the United States, Chile, Mexico, Canada, South Africa, Australia, and Tasmania, which now produce about nine tenths of the copper of the world, were totally undeveloped. Not until the middle of the last century, when the Lake Superior mines were opened, did the production of copper reach large proportions.

Copper has had the strange and happy experience of having two youths. From the dawn of history until the end of the medieval period it was the world's most important metal. Then iron and steel usurped cop-

per's place, and by the beginning of the nineteenth century ferrous products had attained such use and production that they almost totally eclipse copper. When Morse, Bell, and Edison turned to practical use the academic researches on electrical phenomena that earlier scientists had conducted, copper entered its rejuvenation. Its second life seems much more vigorous than its first. Even the most imaginative scientist cannot foresee a formidable substitute for copper in the general electrical field. The earth must continue to furnish red metal that will make possible the extension of the electrical age.

Fortunately, geologists predict that the earth is



WORLD'S COPPER PRODUCTION BY DECADES, 1810–1920

ready to furnish large amounts of copper, provided man is willing to expend the necessary energy. It is hard to estimate even approximately the amount of available copper that the earth contains. The geologist and mining engineer compile and list what the copper companies call their "ore reserve," but it is quite possible that the large producing mines of two

or three decades hence are only partly explored at the present time. A few years in the future the waste piles of mine tailings may themselves be considered as valuable as new diggings. Processes for the recovery of copper from ores have improved so rapidly that already some of the débris from former mining operations is being worked over for the small amount of metal it contains. In fact, the known supply of copper ore in the United States has been increased during the last few years, and it is probable that for several years mining and metallurgical methods have added to the reserve more available copper than was newly extracted during the same period. In some districts the copper made available in the tailings of earlier operations would go far toward equalling current production. Whether or not a large amount of copper is produced depends upon how much people are willing to pay for it. If the price of copper were twenty cents a pound, much more would be mined and smelted than if the price were thirteen cents. Whenever the price of copper rises, there is an addition to the amount of copper that the world can produce under the existing conditions. If the price drops, the world's copper reserves must take a slump because of the new and less favorable conditions. It is similar to offering a man more money if he will work longer hours, or, in the other case, it is like reducing his pay.

Yet the copper resources of the world are relatively limited. Experts have predicted that in twenty years, unless new deposits are found, we shall be confronted

with a shortage of copper similar to conditions before the discovery and development of the "porphyry" mines about 1900. At that time the supply of copper ore in the United States seemed extremely limited. In that case, improvements in mining and treatment of ore saved the situation and made it possible to work these low-grade porphyries, containing about 2 per cent. copper, in competition with "vein" mines carrying higher percentages of copper. These mines of a new type, it was then found, could be excavated with steam-shovels such as those that were used on the Mesabi iron range. Instead of being thousands of feet deep like vein mines they were only a hundred feet or so in vertical depth. The vein mines previously worked at Butte, in Michigan, and in the Clifton and Globe districts were only ten to forty feet wide and dipped steeply into the earth; the porphyries were thousands of feet long and often a thousand feet wide, lying comparatively flat and close to the surface of the ground.

It is hard to say whether such a shortage will actually occur. We can hope that better metallurgical methods and more prospecting will prevent its occurrence, and at the same time see what copper ore reserves are reported at the present time. Figures on the copper laid up in Mother Earth's subterranean vaults are not complete, as many companies do not make public their reserves. When looking over these figures, remember that the average annual world copper production for the last decade was about 2,200,000,000 pounds.

Estimates of the ore reserves of some of the mines are as follows:

Mine	Ore reserves, tons	Per cent. copper	Recoverable copper, pounds
Andes Copper, Chile	138,890,509	1.498	3,330,000,000
Braden Copper, Chile	264,510,000	2.26	9,655,000,000
Chile Copper	688,629,889	2.12	25,500,000,000
Chino Copper, Santa Rita, N. M.	105,385,461	1.53	2,580,000,000
Inspiration, Globe, Ariz.	72,374,741	...	1,380,000,000
Kennecott, Alaska	....	...	490,000,000
Miami, Globe, Ariz.	14,899,834	2.15	447,000,000
Nevada Consolidated, Ely, Nev.	63,401,209	1.58	1,550,000,000
New Cornelia, Ajo, Ariz.	65,000,000	1.45	1,495,000,000
Ray Consolidated, Ray, Ariz.	82,652,220	2.068	2,734,000,000
Utah Copper	362,910,100	1.35	7,840,000,000

Data on the large vein mines are not available, but several years ago it was estimated that there were about 2,700,000,000 pounds of recoverable copper in the principal mines of the Lake Superior region.

Many of the developments that show large ore reserves are of comparatively recent date. A few years ago the figures for the Chile Copper deposits were considerably lower.

Changes have been made constantly in the copper reserves of the world during the last few years, largely because of the great African deposits that are being proved. The table showing world copper reserves, as compiled by F. W. Paine and published in 1920, has been upset somewhat. Recent reports from

the Katanga region in Belgian Kongo tell that there are 70,000,000 long tons of ore proved and under development, running 5.7 to 16.7 per cent. copper, and containing 10,080,000,000 pounds of metallic copper. Other estimates indicate that there may be 300,000,000 tons of ore, which will eventually produce the immense total of 42,560,000,000 pounds of copper. These deposits are in the interior of Africa and at present are hampered commercially by high transportation costs. Russia also contains valuable deposits which are cut off by present political conditions, and these will probably produce 11,000,000,000 to 12,000,000,000 pounds of metallic copper.

These recent estimates revise the statistics on the control of the world's copper resources. Using the most conservative estimates on reserves, American interests control about 68 per cent. of the total, while if more liberal estimates are used the figure would be reduced to 57 per cent. Most of the deposits not under American control are owned or dominated by British capital.

CAPACITY OUTPUT AND RESERVES OF COPPER PRODUCING COUNTRIES [1]

Producing country	Estimated Capacity Output of Copper (metric tons)	Percentage of World Total	Percentage of Total Reserves of World
Western Hemisphere:			
United States	928,000	57.5	34.
Canada	58,000	3.6	3.
Mexico	65,000	4.0	1.15

[1] Adapted from chapter by F. W. Paine in Spurr's "Political and Commercial Geology."

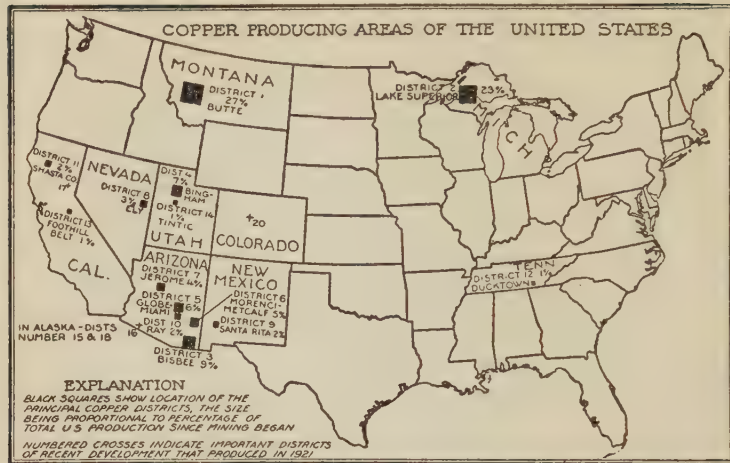
CAPACITY OUTPUT AND RESERVES OF COPPER PRODUCING COUNTRIES
(*Continued*)

Producing country	Estimated Capacity Output of Copper (metric tons)	Percentage of World Total	Percentage of Total Reserves of World
Cuba and Venezuela	12,000	0.7	0.10
Chile	110,000	6.8	37.9 [2]
Peru	45,000	2.8	0.55
Bolivia	12,000	0.8	0.10
Total	1,230,000	76.2	76.8
Eastern Hemisphere:			
Africa	58,000	3.6	11.3
Australia	43,000	2.7	0.95
Japan	125,000	7.7	2.2
Spain and Portugal	42,000	2.6	6.2
Russia	18,000	1.1	0.95
Central Powers	71,000	4.4	0.95
Norway	19,000	1.2	0.55
Sweden	1,000	0.1	0.04
Other countries	6,250	0.4	0.06
Total	383,250	23.8	23.2
World Total	1,613,250	100	100

Percentage of world total reserves owned by capital of various countries: United States, 73.6; British, 20.8; German, 1.05; French, 0.4; Japanese, 2.2; local capital in producing countries, 1.95.

While foreign deposits may supply the world with copper at some future date, to-day the United States holds undisputed first place in copper production. The American copper industry was begun before the white man arrived on this continent, and it flourished

[2] As the large reserves of Chile are compact, distant from the market, and in thinly settled country, this large figure must be discounted in so far as it affects production.



No.	District, State	Production began	Percentage total U. S. 1845-1921	Production in 1921 Percentage	Production in 1921 Rank
1	Butte, Mont.	1868	27	10	4
2	Lake Superior, Mich.	1845	23	19	1
3	Bisbee, Ariz.	1880	9	8	5
4	Bingham, Utah	1896	7	6	6
5	Globe-Miami, Ariz.	1881	6	16	2
6	Morenci-Metcalf, Ariz.	1873	5	2	11
7	Jerome, Ariz.	1883	4	6	7
8	Ely, Nev.	1908	3	2	12
9	Santa Rita, New Mex.	1800	2	2	14
10	Ray, Ariz.	1911	2	2	13
11	Shasta County, Cal.	1897	2	..	..
12	Ducktown, Tenn.	1850	1	3	9
13	Foot-hill Belt, Cal.	1862	1	..	..
14	Tintic, Utah	1880	1	..	19
15	Copper River, Alaska	....	..	11	3
16	Ajo, Ariz.	....	..	4	8
17	Plumas County, Cal.	....	..	2	10
18	Prince William Sound, Alaska	....	..	1	15
19	Burro Mountain, New Mex.	....	..	1	16
20	Lake and Eagle Counties, Colo.	....	..	1	17

on a primitive scale. It is recorded that the settlers discovered copper in Massachusetts as early as 1632, and in 1709 a company was incorporated in Connecticut for the purpose of working copper ores. The copper deposits of New Jersey were worked in 1719, and the copper-mines of Vermont date from the eighteenth century.

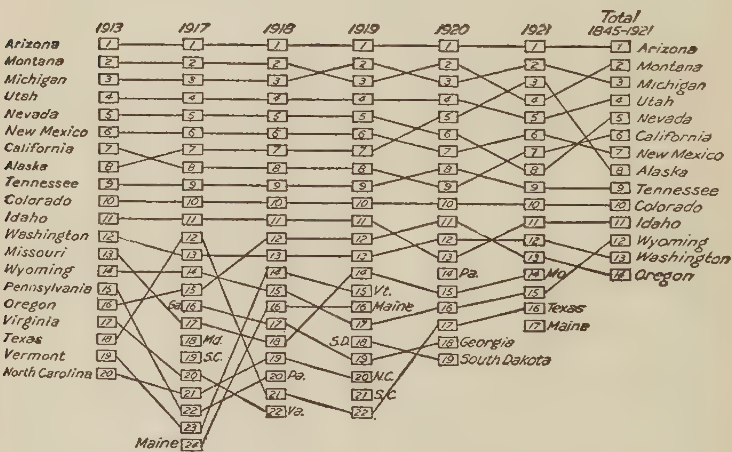
But the real development of the American copper industry began in 1844 when white men began to exploit, as the Indians had bfore them, the richness of the Lake Superior native copper deposits. For years Michigan held sway as the great copper-producing State, but in 1882 Butte, Montana, produced its first copper and the most important copper camp in the world was inaugurated. A decade later the copper industry of Arizona was established.

For the three quarters of a century that the copper industry has existed in the United States, Arizona and Montana are close rivals for the honor of being the largest producers. Arizona, although later to achieve production, ranks first by a narrow margin and is responsible for 28.19 per cent. of the total production. Montana holds second place with 27.06 per cent., while Michigan is third with 23.18 per cent. These three States from 1845 to 1922 produced more than three quarters of the total copper mined in this country. Utah with 8 per cent. of the total ranks fourth. The fourteen important copper-producing States and their record during that period, as compiled by the United States Geological Survey, are:

Copper produced in the United States, 1845–1921, by States

[Smelter output]

State.	Pounds.	Per cent.	Rank.
Alaska	675,257,584	2	8
Arizona	8,500,925,933	28	1
California	796,185,053	3	6
Colorado	290,605,186	1	10
Idaho	114,450,615	.....	11
Michigan	6,961,378,104	23	3
Montana	8,061,394,471	27	2
Nevada	957,508,434	3	5
New Mexico	716,203,395	3	7
Oregon	15,549,894	.....	14
Tennessee	398,553,000 [1]	1	9
Utah	2,408,562,961	8	4
Washington	17,695,070	.....	13
Wyoming	31,585,120	.....	12
Other States and unapportioned	161,800,750	1	....
	30,107,655,570	100	....



From "Mineral Resources, 1921"

CHART SHOWING RANK OF STATES PRODUCING COPPER, 1845–1921

[1] Approximate production.

While Arizona is credited with being the most important copper-producing State, Butte, Montana, is by far the most important and interesting copper-producing camp in the world. More than one quarter of the total amount of copper mined in the United States has come from Butte.

Two adventurers in search of mineral wealth, so the story goes, crossed the Great Divide from Virginia City one evening in May, 1864, and came upon a small pit which some forgotten miner had abandoned. From this six-foot pit has sprung the Original Mine of the Anaconda Co., now only one of the many in the Butte district. The barren steeply rising hill or butte on which the pit was located provided the name that the metropolis of Montana now bears. Gold, not copper, was the metal that Butte's founders were seeking, and for three years the gravels of the regions were washed and made to yield yellow metal. Silver was the cause of Butte's next epoch of development, and from 1865, when the first vein was found, to 1893, when the collapse in the price of silver occurred, silver mining was Butte's most important industry. The climax of the production of silver ore was reached, however, in 1887; the silver and copper periods overlapped.

Before 1880 the idea that Butte would become famous as a great copper producer would certainly have been ridiculed by mining engineers and geologists of the day. But the young manager of a silver mine believed that Butte Hill was rich in copper, and, succeeding in making a group of California capitalists think so also, he acquired a large part of the hill

and set out to prove his belief. Thus an unschooled Irishman, Marcus Daly, established Montana's copper industry. He conducted mining and smelting on a scale that Butte had never seen before. Night and day men probed the earth for the rich copper veins, a hundred furnaces raised their stacks and smoke, and lumberjacks denuded whole forests to provide the timber to shore up excavation, cross-cut, and tunnel. Mountains of gray-green refuse and hills of black slag were spread over the landscape, and on the surface Butte became an ugly scar in virgin country. But underground, Marcus Daly was creating the first of Montana's great copper-mines. In 1872, earlier than Daly's exploitation of the deep, rich copper, Senator W. A. Clark had made the first successful development of the copper veins of the Butte district. At this time the ore had to be taken overland four hundred miles in wagons until the railroad was reached at Corinne, Utah, and then it was shipped by rail to the Eastern smelters or even to Swansea in England. In 1879 there was erected near Butte a reduction plant that cared for the ore of that district. From these beginnings, in a short forty years, Butte had given a metal-using world more than two billion dollars in mineral wealth, a large part of it in copper. It has produced more copper and silver than any other district in the world, and from it has come one sixth of all the copper mined in the world.

Volcanic action brought this wealth of copper to Butte. The butte itself is the eroded remnant of a small volcano, and all the rocks of the ore-bearing area are igneous. The history of the copper minerals that

are found there is one of ascending waters that carried a copper burden to the veins above. Chalcocite, more familiarly known as glance, is the principal copper mineral. Butte mines are nearly an exclusive residential section for members of the copper-sulphur mineral family. The other important Butte copper minerals are bornite, enargite, and cupriferous pyrite, while covellite, tetrahedrite, and chalcopyrite are less common. The reason why the early settlers at Butte mined silver instead of copper was that the great wealth of copper was hidden underground, and it is only after the deposits have been penetrated two hundred to four hundred feet that the wonderful deposits of copper ores are found. They are at this level because of the action of what the geologist calls "secondary enrichment." The upper levels of the veins have been robbed by descending waters to enrich the lower copper deposits. Thanks to the extensive development work that the disputes over ownership of the ore bodies made necessary, the way in which the veins of the Butte region run has been revealed. The rocks of the district are traversed by a multiplicity of joints and fractures; in many places, by some gigantic disturbance, the rocks have slid over one another, or "faulted," to use the geological term. Because of this, two great mines some distance apart often send their shafts down into what was once a single vein.

Arizona, the State that ranks first in copper production in this country, has five districts that yield a large amount of copper. In 1921 Arizona produced 31 per cent. of the copper of the United States, and it is credited with the largest part, 28 per cent., of the

total production since 1845 despite the fact that mining there did not begin on a large scale until about ten years later than at Butte.

The famous Copper Queen mine is contained in the Bisbee or Warren district, which ranks highest in production in the State in point of total production, although in recent years it has been surpassed by the Globe-Miami district. This mining center is very close to the Mexican border. Bisbee, similarly to the Clifton-Morenci district, the second largest total producer in Arizona, is the product of an invasion of limestone by granite magmas that carried copper and iron and deposited it in the highly heated and changed limestone. In many cases percolating waters have concentrated the ore at lower levels by secondary enrichment, and this process has been responsible for the "cave" ores for which Bisbee was so long famous. Near the surface of the copper-invaded limestone, there were formed caves of irregular shape, some of them three hundred feet wide and seven hundred feet long. These were decorated on their inner surface with green malachite and blue azurite, set off with stalactites of calcite. Such artistic oxide ores are now virtually exhausted, and it is the more prosaic pyrite, or iron sulphide, that has associated with it the copper-containing chalcopyrite and glance, which now produces most of the copper of the Bisbee district. Metallurgical processes are progressing so that even the relatively lean masses of the main porphyry are being exploited.

Much the same genealogical story can be told about the other copper-producing localities of Arizona. The

Globe-Miami district ranks fifth in the country as well as second in the State in point of total production, but in recent years it has been the leading producer of the State and the second best copper district in the country. Mining for silver began in the region in about 1880. At Globe the deposits consist of lenticular masses replacing limestone in dark igneous rock. At Miami, only six miles from Globe, the ore minerals are disseminated in the shattered schist and granite.

The copper deposits of the Morenci-Metcalf district were discovered in 1872, but they remained undeveloped for a long period because of their low grade and their distance from a railroad. Now in total production this region ranks sixth among the districts of the country. The ores here occur as contact deposits in limestones and shales intruded by porphyry. The Jerome district is another important Arizona locality, which in total output stands seventh among the copper districts of the country. The ore occurs in schists, and consists of replacements of the schists by chalcopyrite, associated with pyrite and zincblende. The Ray or Mineral Creek district deposits are similar in geological condition to those of the Miami district, and though it began production in 1883, it has become an important producer only since 1911.

The Keweenaw peninsula in Michigan, jutting sharply out from the southern shore of Lake Superior, was for a long period the principal American producer and has always been an important one. The region is also unique as the only one in which there have been produced large quantities of native copper. Both in total production and for the single year 1920,

this district ranked third among those in the United States. The Indians first discovered the Lake Superior deposits and worked them on a scale astonishingly large for such primitive people. But the modern pioneer of the great mining activity on the Keweenaw peninsula was Douglas Houghton, the first State geologist of Michigan, who was appointed in 1837. Just two hundred and one years earlier, a book by Lagarde published in Paris had given an account of the occurrence of native copper near Lake Superior, and at even earlier dates Jesuit missionaries and early *voyageurs* mentioned the extensive use of copper by the Indians. It was a century later, in 1763, that a practical Englishman, Alexander Henry, visited the region, and a decade later he unsuccessfully attempted mining operations. This early history had as little influence on the final development of the Lake Superior copper-mines as did the Indian exploitation in pre-Columbian days. Houghton's scientific description of the copper deposits contained in his report made in 1841 drew attention to the region, and when the Chippewas, on March 12, 1843, ceded the land to the Government, there followed a speculative craze which lasted for three years. The first mines opened were veins of the Eagle River district, which carry both native silver and native copper and were not the layers of conglomerate and amygdaloid which have become the great producing lodes of the region. Shortly afterward the lodes of mass copper in the Ontonago district at the south end of the region were developed and became noted for the large boulders of metal that were found. In 1856 the first of the rich copper de-

posits in the amygdaloid layers, such as the great Quincy mine, was opened up, and when E. J. Hulbert, John Hulbert, and Amos H. Scott, in September, 1864, uncovered a copper-bearing conglomerate, thus discovering the Calumet lode, a new epoch in Michigan copper was ushered in. The later history of Lake Superior mining is one of financial venture and consolidations, combined with improvements in mining and metallurgical methods. While the Superior mines were virtually alone as copper producers in this country until 1880–90, during the last thirty years they have had to sustain the rivalry of the great Western copper deposits.

If you took a sharp knife and sliced off the Keweenaw peninsula from one of its shores to the other you would see that it is made up of a large number of layers of rocks dipping toward the northwest at an angle of from thirty to eighty degrees to the horizontal plane. Starting from the west side of the sliced section and going eastward, there are layers of sandstone, then layers of conglomerate. The rest of the sloping layers are made up of igneous rock in which there are interposed the copper-containing conglomerate and amygdaloid layers. All of these rocks were once horizontal instead of sloping, but after they were formed a great earth movement thrust them into their present position. The copper-mines follow the pay rock in the long sloping layers of conglomerate and amygdaloid rock, which is a comparatively easy matter.

A mountain of copper ore, the largest in the world in ore production, yields most of the metal produced

in Utah, which ranks fourth in total production in the country. This is the porphyry mass which contains disseminated primary chalcopyrite and pyrite, with secondary covellite, chalcocite, and bornite which have sufficiently enriched the whole mass to make it pay ore. The mass of ore sticks up in the air sixteen hundred feet and is a mile long and half a mile wide. It is overlaid by a capping of worthless material, averaging 115 feet thick, which must be removed before the ore can be exploited. At the end of 1920 the total ore reserves of this deposit amounted to 364,130,800 tons averaging 1.35 per cent. copper, not including the parts that have not been prospected or tested. This is the second largest developed copper ore body known. When the mine was first opened the ore was extracted by underground workings, but it soon became apparent that it would be profitable to use steam shovels and the open cut method, despite the necessity of removing the large amount of over-burden. The mountain of ore is now being leveled and sent to concentrators and smelters at the rate of ten million tons a year, yielding about eighty thousand tons of copper. The ore that was mined in the early days at Bingham was not the disseminated material in the porphyry, but irregular replacement deposits in limestone. As late as 1900, before the development of modern methods of ore treatment, the great Bingham deposits containing small percentages of copper were rightly considered of little immediate value. Of this property "The Engineering and Mining Journal" in an editorial headed, "A Doubtful Copper Prospect," wrote as follows in its issue of May 29, 1899:

It would be impossible to mine and treat ores carrying 3 per cent. or less of copper at a profit under the existing conditions in Utah. On the company's own showing, therefore, the more ore it has of the kind it claims the poorer it is.

The editor was doubtless right when he wrote; but in 1915 the Utah Copper Co. produced 156,207,376 pounds of copper, from ore which yielded only 18.82 pounds to the ton, at a net cost of 7.48 cents a pound; sold copper at an average price of 17.679 cents a pound; paid 42½ per cent. dividends on its stock; and showed a surplus after dividends equivalent to more than 67½ per cent. on its capital stock. D. C. Jackling and R. C. Gemmel were largely responsible for proving the editorial wrong, and they deserve part of the credit for developing several of the large porphyries which contain the principal part of the American reserves.

Utah ranks third in both possible and proved reserves of the world, with Katanga first in possible reserves and Chuquicamata first in proved reserves.

Before 1903 Alaska had produced very little copper, but in 1922 it ranked fifth as a producer in this country. Most of Alaska's copper has so far come from the mines in the Copper River district, which operate on very rich chalcocite ore. This rich region was tapped on a considerable scale only with the completion in 1911 of a two-hundred-mile railroad built to serve it, and fortunately these mines came into quantity production just in time to benefit by the war demand and war prices for copper. These deposits were formed by ascending thermal waters, which replaced limestone with copper, and the diggings of to-day do

not show the benefits of secondary enrichment. In the ice age, glaciers scooped off the original upper parts of the deposits that had been oxidized by the surface-waters, and at the same time these great sheets of ice swept away the next lower layers that had been enriched. Post-glacial times have been too short to allow nature again to concentrate surface copper at lower levels, but so rich are the primary sulphide ores formed in limestone that man is hardly warranted in expecting their value to be increased by enrichment.

Nevada, fifth in line in total copper production since 1845, owes its place chiefly to the Ely district. In this region most of the producing ore bodies consist of great masses of porphyry which have projected themselves into limestone. These are mined in part by the open cut method similarly to the Bingham deposits, and they contain only about 1½ per cent. of copper.

Ducktown, Tennessee, is the only district east of the Rockies, other than the Lake Superior region, that is important as a copper producer; and it is nearly as well known for its sulphuric acid as its copper. In smelting this ore for copper, sulphur that was harmful to vegetation was given off in the smelter fumes, and to prevent damage to near-by farms, the Tennessee courts fixed a maximum amount of sulphur that might be expelled into the atmosphere. This forced the smelters to utilize the sulphur in the ores instead of wasting it, and it led to the manufacture of sulphuric acid, which is now used in fertilizer on a large scale.

At one time California ranked second only to Michigan as a copper producer, but in total production it now ranks as the sixth State. The bulk of the Cali-

fornia production comes from the deposits of Shasta County, which are of the porphyry type. Part of the copper is also obtained from mixed ores, in which the copper is subordinate to silver-lead and pyritic gold ores.

New Mexico's copper history dates from the eighteenth century, when native copper was sent to Mexico for coinage purposes. Important modern production began in 1912. The Santa Rita district is the principal producer and in 1921 ranked sixth. The ore body is of the disseminated type and of considerable extent, but, unlike most of these ores, there is an appreciable amount of native copper present.

Colorado and Idaho have appreciable outputs of copper ores, but most of the production is incidental to the mining of ores of other metals, principally lead and zinc. In Georgia, Oregon, Vermont, Washington, and Wyoming copper deposits are also found and worked, but these are of minor importance.

Our next-door neighbor to the south, Mexico, is credited with 4.9 per cent. of the production of the world in 1918 and, had conditions been more settled politically in the few years preceding, it probably would have shown a much larger production. Geologically the deposits are much like those of our Western States, as they are located in the same kind of country. The Cananea district in the State of Sonora is the most important copper region in Mexico and lies only about forty miles southwest of Bisbee, Arizona. The Boleo mines in Lower California are the second largest producers in Mexico.

Canada on our north holds fifth rank in the copper

production of the world. More than half of this is from British Columbia, principally from the Boundary district, so named because it is not far from the United States line. Ontario is responsible for one third of the Canadian production and is famous for the nickel-copper ores of the Sudbury area. Most of its copper is obtained from these ores, which contain from 1 to 2.5 per cent. of copper. As late as 1916–17 large and rich copper deposits were discovered in Manitoba, but this area is not yet opened up for large-scale exploitation, although the future promises much. Upon the arctic coast in the Northwest Territories, according to the report brought back by the Canadian Arctic Expedition, there are deposits of native copper over an enormous area that resembles the important Lake Superior region of our own country. Evidently, even in these modern days, there are lands to conquer. The report of the copper possibilities of the far north says:

> The copper-bearing rocks would seem to extend along the Arctic coast both east and west of the Coppermine river for about 500 miles in all, and probably many of the smaller islands off the coast are also of the same rocks, and the total area of these rocks undoubtedly amounts to many thousands of square miles. Comparing the early accounts of the occurrence of native copper on Lake Superior with the accounts which we now possess of the copper on Coppermine river, and considering the enormous extent of the northern deposits, we have reasonable grounds for hope that before many years the Coppermine area will produce as much copper as is now mined in Northern Michigan.

Not only does Chile contain the largest mine in the world and the greatest known copper reserves of the

world, but it now ranks second only to the United States with one twelfth of the world production to its credit. Chile is in its second important copper production period of modern times. Between 1870 and 1882 it supplied the bulk of the copper used in the world, and after this time production declined considerably until 1900, when the present revival set in. The earliest copper mining in Chile occurred before the advent of the white man, and to-day at the principal copper-mines there may be seen the old Indian workings that honeycombed the hills of copper in search of rich streaks in the veins. The Chuquicamata deposits are the most extensive so far proved in any part of the world, and it is estimated that they contain seven hundred million tons of copper ores averaging 2.12 per cent. copper. They are comparable in structure to the great porphyry deposits of the United States such as at Bingham, Utah, and are worked in much the same way by the open cut method.

The hill on which they are found is 9890 feet above sea-level in an arid and desolate country, and is about two and a half miles long and a third of a mile wide.

This Chile Copper Co. mine and two other important holdings, the Teniente mines of the Braden Copper Co. and the mines of the Andes Copper Co. that are not yet being worked, are all American-owned. In these properties are concentrated the important copper reserves of Chile; it is estimated that these mines could continue their present capacity output for from 150 to 200 years.

In Peru the second largest copper producing mines of South America are located. They now stand

seventh in world production. As in Chile, these are largely American-owned. In only a few localities are ores mined for copper alone, and in nine tenths of the output the copper has come from silver-copper or copper-silver ores. Bolivia, Venezuela, and Argentina are also small producers of copper.

Japan's copper-mines, which stand third in world production, are strictly Japanese in ownership and management, as the state owns all ores and grants the right to work them to individuals or companies of Japanese nationality only. Until a few years ago, Japan's production exceeded that of Chile, but recently copper has been imported on a rather large scale. Geologists believe, however, that in the future Japan will be able to supply its own needs. Copper is the chief metallic product of Japan, and it occurs in virtually every province of the island. It has been mined from time immemorial. The principal mines include the Ashio, Kosaka, Besshi, and Hitachi, each of which has produced more than ten thousand tons of copper in a year.

Rio Tinto has been a synonym for copper ever since the Phenicians worked this great Spanish copper-mine as early as 1240 B.C. In reserves and in the amount of ore that has already been extracted, the Spanish copper deposits are remarkable. The ore already mined is estimated at more than 125,000,000 tons, the proved reserves are more than 230,000,000 tons, and in 1920 there were 25,000,000 tons in the stock piles undergoing the lengthy leaching process which is used in extracting the copper. Like those at Bingham, the deposits at Rio Tinto are worked mainly

A MOUNTAIN OF COPPER

An airplane view of the Utah Copper Company's mine at Bingham, Utah.

THE GREAT COPPER "CAMP" OF BUTTE, MONTANA

A view of the Butte mines, looking west.

by open cuts, and this method has been followed from the earliest days, though because of the depth of some of the workings a system of stoping sometimes is used. To-day railroads run on the tops of waste piles of over-burden that were placed there by manual labor in the days of the Romans. Rio Tinto has always been controversial ground for geologists. Some believe the deposits to have been formed by the intrusion of molten sulphides, segregated from an igneous magma, but others assert that they are replacement deposits.

Virtually all the other European countries produce some copper. The Mansfeld shales in Germany yield a fair quantity of the metal, but Germany is dependent on outside sources for the large bulk of its copper. Under the old régime Russia supplied some of its internal demand for copper from its own mines. Norway and Sweden contain important copper-mines, which are usually low in copper values. England still obtains a small amount of copper from the Cornish tin-mines that in the bronze age conveniently furnished both the tin and copper for the early Britons. France and Italy produce considerable quantities of copper-containing pyrites. Finland has recently developed mines that promise to be as important as those of Norway and Sweden. They are also of the same type. In Siberia, eastern Russia, and the Russian Caucasus there are deposits, not now worked, that promise production sufficient to place that country among the important copper countries.

The island continent of Australia in the past has been relatively more important as a copper producer than it is now. The best-known Australasian mine,

perhaps, is the Mount Lytell in Tasmania. It is an old and steady producer and is one of the lowest grade profitable mines in the world.

Africa is becoming of increasing importance as a copper producer because of the deposits of the Katanga region of Belgian Kongo. These are very rich in copper, some of them running as high as 30 per cent., and the developed reserves alone assure a hundred years' supply of 8 per cent. ore. Other important African deposits are located in the Union of South Africa and Southern Rhodesia, whose mines are geologically a part of the Katanga district.

China is a somewhat unknown quantity as to copper resources because of the backwardness of its people, who, unlike the Japanese, work the mines in the same way that their grandfathers did before them. China's chief mine, the Tung-chuan-fu, has a yearly output of about a thousand tons of copper, and this district has been worked for hundreds of years; but those mines that have been investigated promise little copper if worked by modern methods on a considerable scale.

When the great copper-mines of the world are being described, we must not forget one of them that in area and closeness to all of us is the most important in the world. The city in which you live is a vast copper-mine, but the ore is too valuable in most cases to disturb for its low copper content. There is a gradual slow process of concentration in progress during the daily life of the city. Copper, brass, and bronze articles become obsolete or damaged and finally find their way to the bins of concentrate. You will find these storehouses of city-mined copper in some side street

in the factory district, with the signs of "Junk" and "Old copper and brass bought for cash; best prices." In the statistics of copper production, salvaged copper is referred to as "secondary copper," and it is an important factor in the copper market. Each year between 600,000,000 and 700,000,000 pounds of such refined copper from secondary sources are produced in the United States.

The copper-mines that civilization is creating have been drawn upon in times of dire need. When Germany was cut off from customary imports of copper during the war, roofs, church bells, kitchen pans, doorknobs, and all sorts of copper-containing articles went into the melting-pot to supply the German armies with red metal.

The war caused another interesting case of the exploitation of secondary copper. Chinese copper coins contain 85 per cent. copper. In 1916 copper rose in price to such an extent that Japan found it profitable to import large quantities of these coins and extract the copper. One concern alone in 1917, regardless of the effect on Chinese finances, contracted for two hundred thousand tons of these Chinese coins. The sixty thousand tons of refined copper a year from this secondary source allowed Japan to make heavy exports of copper during the war.

CHAPTER IV

WINNING METAL FROM THE EARTH

In man's struggle to free copper from the other elements or rocks and minerals with which it is combined or mixed, he supplements and improves upon the methods that nature herself has used in geologic times to create the specially rich deposits of copper-bearing material that man calls mines. From the time, eons ago, when perhaps other elements in the heat of stars combined to form copper, until the final electrolytic refining of to-day, which purifies copper to do the world's work, concentration of the copper has been the goal. During the ages that the earth's crust was taking its present form, nature was not always successful in her concentrating processes; in fact, one would suspect that at times she lost interest in storing up minerals rich in copper and had a fling of extravagance. But we have seen how rising hot water scattered copper minerals in rocks near the surface and later how the waters of rains gathered this copper together to form a concentrated bonanza layer as a prize package for lucky and foreseeing miners, and we have seen how large volumes of rocks were impregnated with copper or copper minerals. After nature performed her process of concentration and after man has discovered where she has laid up her treasure,

then the human mind must evolve the best methods of obtaining red metal from unpromising earth.

Man's first step in his concentration of copper is mining, and the way in which he goes about it depends upon the condition in which geological processes have left the ore. If the deposits consist of rich veins, as they do at Butte, he must sink deep shafts and run lengthy tunnels or drifts through which the ore may be carried to the surface. On the other hand, if a mountain of copper has been created,—a copper mountain that contains only 2 per cent. metal at the most,—such as at Bingham, Utah, then it is cheaper and easier to call upon steam-shovels and railroads to transport the whole hill to the concentrating-plant. By these two methods, underground and open-cut mining, the mining of the world is done.

If you saw a car-load of copper ore, unless you were well acquainted with copper mining, you would probably think that it was only so much rock. You would be about 98.37 per cent. right, for the average recoverable content of copper in copper ore produced in this country in 1920 was only 1.63 per cent. From every ton of copper ore an average of only 32.6 pounds of copper was obtained. This seems a very small amount,—the value of the metal to the ton, including forty-six cents' worth of gold and silver, is only $5.02 when copper is fourteen cents a pound,—and it would be except for the fact that large quantities of ore are mined and treated every year. The value of copper production in 1920 was $222,457,000, while in the peak year of 1917 it was $514,911,000. It is the fourth largest mining industry in the country, only coal, petro-

leum, and iron surpassing it. More than forty thousand men were employed in 226 copper mines of the country even during the poor year of 1919, and this is nearly as many men as were then required in the iron mines.

When a copper deposit is suspected the first step toward mining is to prove that the ore is there. Sinking a large shaft that would allow a close-up inspection of the underground strata used to be the only way by which riches of the earth could be discovered, but modern methods send a drill down in the small round opening that it makes to bring back the desired information about the deposits. Unless valuable mineral is exposed at the surface and there is a good chance of the shaft paying its own way down from the surface of the earth, the drill method is usually used to-day. Often the familiar "churn" drill, similar to the ones you have no doubt seen drilling wells or foundation test-holes, is used, but more frequently on important developments black diamonds cut the way. A hollow steel rod, in whose lower cutting periphery small black diamonds are set, will cut through rock, and from the cylindrical core that rises in the pipe the kind of deposit can be determined. Even after the shafts are dug and the underground workings are in full sway or after the steam-shovels have begun their devourings, drilling is used to guide further exploitation of the mine.

Say "mine," and the ordinary person who uses the products of mines daily but has never seen one will usually think of a hole in the ground. His idea is correct, to be sure, but he probably does not realize the

elaborate scale on which mines are built. If a modern sky-scraper, even the largest of them, were buried in the ground it would be small compared with some of the mines from which copper ore is obtained. The Woolworth Building is eight hundred feet high, while shafts more than a mile, 5280 feet, deep lead to copper diggings. Hundreds of miles of underground passageways are dug. Great and extensive elevating systems are installed and miles of subterranean electric railways are built. Running water requires large pumping plants to remove it, and fresh air is forced into the depths by large fans. The mine is a community in itself. And, like a huge office building, it is not a dwelling-place for man, though it may be for mules and horses, who often live for years below ground. Unlike a sky-scraper, the mine is built from the ground down and not from the ground up. The chief idea is not to place material into the mine structure but to take it out. And the finish of the interior is that which is fashioned by the tools of the men who spend their working days there.

When the miner goes to work in the morning, he reports at the top of the mine's "elevator" shaft. There he enters the cage, as the steel platform attached to a heavy wire cable is called. A hoist driven by a steam or compressed air engine or electric motor lowers the cage down a timbered and fire-proofed shaft to his "floor," which may be from 3000 to 4000 feet below. When the miner arrives at the proper point in his downward journey he scrambles out into a station, which, like all the rest of the underground workings, is a cavern hollowed out by man. From this room he

enters a "level" or tunnel. This is one of the main corridors of the mine, and on the way down many similar to it have been passed. Traveling along the level he meets steel ore-cars hauled by a small electric locomotive that derives its power from current carried by a copper trolley-wire. Near by this raiload there flows a miniature river hurried on its way by gravity. Even the atmosphere the miner breathes may be controlled by machinery, and he feels the gentle rush of air created by distant ventilating-fans. Forests have been sacrificed to provide the great sawed timbers that support the workings and prevent them from caving.

He turns a corner into a cross street running at right angles to the level. If you asked him where he was he would say, "In a cross cut." This tunnel takes him closer to the chamber which will be enlarged through his mining of copper ore. Finally this chamber, or the "stope," is reached, and the day's work begins.

When the excavation of a stope is begun a tunnel called a drift is driven into the area that is to be robbed of its ore. Explosives do the heavy work after they have been placed in a position so that they can. The first step toward removing rock in any part of the mine is usually the drilling of holes preliminary to blasting. Air-drills are used almost exclusively to penetrate the rock as deep as seven to ten feet. After the explosive, usually dynamite, is placed snugly in these holes, it is fired by means of a fuse and copper primer, or an electric blasting machine that operates through a copper wire. This shatters and breaks the

ore to the floor of the stope, and it is then ready for loading into ore-cars either directly or after sorting to remove waste pieces. The size of the excavation and the methods by which it is hewn out of the rock are dependent upon the character of the rock, the size of the ore veins or bodies, and a number of other factors. Whether the miners start at the top of the volume of ore and dig their way downward or whether they tackle the ore from below and undermine it also depends upon how well the rock walls will support the stress and the plan of the mining operations.

In some cases it is not practicable to run the necessary trackage for the ore-cars all the way up to the stope, and then the ore is shoveled or chuted to the nearest level equipped with transportation facilities. Often inclined shafts, called "winzes," between floors or levels of the mine are cut in order to allow the ore to flow by gravity from the stope on one level into ore-cars on the level below. The engineers have found that it is cheaper to let the ore carry itself to installed trackage and go to the trouble of raising it an extra hundred feet or so than to construct a special branch of the mine railway to haul out the ore.

The cars carry the ore to the shaft, where they are either dumped into large bins or receiving-pockets or the cars themselves are rolled upon platfoms, called cages, and hoisted to the surface. When receiving pockets are used to store the ore at the junction of the levels and the shaft,—and this is the usual method,—skips, large containers holding as much as ten tons of ore, are used to carry the ore to the surface, where it is dumped and stored in the main ore bins until it

can be transported to the concentrating-plant or smelter.

When the earth is robbed of its copper treasure, a void is created that must be reckoned with. The rock above is quite willing to drop down into the vacant space unless the miner provides a substitute support for it. At one time timber performed this function, but as the forests diminished and wood became a costly replacement of rock other methods have been used. Often the filling-material of worked-out stopes is waste rock that has been mined in getting to the ore. Paradoxical as it may seem, rock fills much more space after the miner has broken it up than it does in its natural state. This is because of the air spaces in broken material. The mined ore itself is often used temporarily for supporting excavations, and it may serve in this capacity for months before it is sent to the surface to be smelted. In other methods pillars of ore are left standing to carry the weight of the superincumbent rocks, or artificial pillars are built of timbers and waste rock.

If the mine excavations are narrow the timber support may consist simply of single timbers called "stulls" bridging from wall to wall. For wider openings "square-set" timbers consisting of a framework of heavy wood are used. Cribs, built of criss-crossing hollow squares of timbers, are also employed in holding up hollowed-out rock.

In one system of mining, the supports are purposely made so weak that at the proper time the worked-out portion of the mine will cave in. After the upper part of the mine has been exploited by ordinary under-

ground methods, the whole honeycombed block of ground is weakened and allowed to crush down. Then a main level is driven a hundred feet or so below the bottom of the floating mass of old mine timbers and waste, and mining by the caving system begins. Winzes are cut upward and the area just under the caved-in material is stoped out. When all the ore possible has been taken out, this part of the mine is allowed to cave in. This is continued downward until finally the main level is reached and the process starts again. Sometimes a variation of this method of mining is used and the ore excavation begins at the bottom of the hundred-foot layer of solid rock instead of at the top. When this is the case the remainder of the solid rock is allowed to cave in along with the floating material on top, and excavation is continued in the half-broken rock. Caving methods are used in some of the Arizona and Nevada copper fields.

It is hard to realize the vast extent of the diggings in an underground mine no matter how impressive a photograph of the surface buildings may be. The total length of the underground passageways of the Anaconda mines at Butte alone stretch seven hundred miles, and thirty-five miles are being added each year. The volume of excavations from which the ore is actually extracted is ten times that of the passageways. In mechanical and engineering equipment as well as in mere extent the important underground copper mines would awe us if we could go and see them.

A quarter- or half-mile below the surface fully equipped engine-rooms may be found. Some of these contain the pumping engines that continually rid the

lower levels of the mine of the ever-encroaching water. Elsewhere large ventilating-fans will be found, and electric power substations that regulate the current for the electric locomotives are also buried in modern man-made caves. The power cables have special entrances to the depths of the mines through holes made by the diamond drill. Extensive communication systems of telephones, buzzers, and bells are installed as a part of the operating and safety systems. In some cases the large hoisting-engines whisk the heavy ore-skips at the speed of nearly a mile a minute. For safety the brakes of these powerful pieces of mechanism must be strong, and their control must be as exact as that of passenger-elevators in large office buildings in cities.

Underground transportation in mines has undergone a revolution in the last few years. Just as the automobile has relieved the horse of the burden of street traffic so the electric locomotive has displaced the mine mule. In former days the mules and horses that hauled the ore-cars over the rails often lived their lives in the depths of the mines. Locomotives propelled by compressed air began to supersede the animals, but this type has given way to either the trolley or storage-battery electric locomotive.

Besides the continual struggle with the ore-bearing rocks that is the reason for the existence of the mine, the operators of underground mines must fight fire, water, and bad air. When timber is carried into the mine to supply the supporting power of the ore that is removed, it brings with it the possibility of fire. This fact is, indeed, one of the reasons why the use of tim-

ber is on the decline. Extensive fire-fighting and fire-protective systems have been installed in many mines. Defective electrical equipment and incendiarism or carelessness are the most common causes of fires, but fires from these causes are generally discovered and extinguished before they become serious. On the other hand, spontaneous combustion is responsible for most of the large fires. Movements of the ground, high temperatures of the rocks themselves, and decomposition readily set fire to inflammable substances such as tarred rope, canvas, dry timber, manure, and hay. Even the heat resulting from oxidation of fine broken sulphide ore is sometimes sufficient to set fire to timbers. Large and troublesome fires are often combatted by depriving them of the air that is necessary for their existence, and if they are caught young enough this smothering method is often successful. In some cases, however, the mine fires are older than many of the miners themselves; for instance, the St. Lawrence mine at Butte has been on fire since 1889. Regions on fire are reached by water sent down through diamond drill holes in many cases, and one of the latest methods used is to accompany the water with fine waste mill tailings that gradually fill up the excavations inhabited by the fire. A layer of artificial stone is used to fireproof the shafts and main levels of many of the large mines, particularly in the Butte camp. The timbers that line the passageways are covered with light chicken-wire, and a coating of Portland cement mortar is shot on with a gun-like machine that mixes the mortar at the same time that it applies it.

Water is troublesome in a mine in two forms, in the liquid state as we ordinarily see it and in the air. Ordinary water is handled by extensive pumping systems or special skips that remove the water from sumps into which it is allowed to run at the bottom of the shafts. When the lie of the ground permits it, special drainage tunnels, called "adits," may be run out horizontally to the surface. When the water is in the air it is handled by the ventilating-systems that keep the air of the mine pure and fit for the miners.

A constant change of air is needed in the most remote corner of a copper mine, not only because a continuous supply of oxygen is needed for men, animals, and lights, but also to remove the gases from fires and blasting operations, and to reduce high heat and humidity. Although copper mines are free from the noxious and explosive gases that cause so much danger and damage in coal mines, still, because copper mines are often deeper, the amount of heat that must be removed by ventilation is in many cases greater. Men and animals in working give off an amount of heat that must be reckoned with, but a far larger amount is emitted by the decaying of the mine timbers and the electrical apparatus. Relatively large amounts of heat are thrown off into the mine by the electrical equipment; it is estimated that such equipment consuming approximately 7350 kilowatts will increase the temperature of five hundred thousand cubic feet of dry air 13.7 degrees Fahrenheit each minute. As the depth of a mine increases the rocks become hotter, and the ordinary increase amounts to about one degree for every hundred feet of depth. Rock tem-

peratures as high as 158 degrees Fahrenheit with air at 135 degrees have been encountered in some deep mines, and even under these conditions mining has been carried on, though not for long periods. These excessive temperatures are the exception, but in some of the deeper copper mines temperatures up to 110 are frequently recorded. The elaborate ventilating-systems must not only reduce the high heat but also remove the air containing large amounts of water vapor. High humidity is just as objectionable a condition as high temperature from the point of view of the mine worker. In the Anaconda mine at Butte, fans in twenty-nine air-shafts handle more than two million feet of air a minute. As there are approximately five thousand men at work at one time in the mine, each man is allotted four hundred cubic feet of air each minute. Proposed installations will increase this amount to six hundred cubic feet. Elaborate devices are employed to speed the air through the shafts and levels with the least possible resistance. In addition to fireproofing the timbers with cement mortar, slabs of smooth-surfaced concrete are fitted in between the projecting posts, and the levels and shafts are thus made as slippery to the air as the modern concrete pavement. The paths that the air must travel are carefully mapped, and air-tight doors are erected to keep it out of the passageways where it should not go. All equipment in the underground tunnels is designed so as to offer the least possible obstruction to the air. In some cases the large ventilating-fans cannot force the air into stopes that are being worked, and where such dead ends occur smaller portable fans boost and

relay the air through canvas or metal pipes leading to the face of the workings.

The deepest copper mine in the world is one located in the Lake Superior, Michigan, district. It is No. 5 shaft of the Tamarack mine, which has reached a vertical depth of 5308 feet, just a little more than a mile. In the mines at Butte depths of 3400 to 3700 feet have been reached, while the equipment installed in certain mines will allow a deepening of the mine to five thousand feet without further change. How much deeper mines of the future will be is a question. There is little indication that the ore in most of the present deep mines will be exhausted at still lower levels. When depths of 7000 to 8000 feet are attained the safe working limit of a rope supporting only its own weight would be reached, but this hindrance to extremely deep mines can be overcome by hoisting in stages. Even now one-stage hoists of more than 3000 feet are uncommon. Other difficulties come with depth, however. These include high temperature and excessive pressure on the rocks, which sometimes causes them to explode or flow.

We have seen how nature in some instances has been kind enough to create veritable mountains of copper-containing rock. It is true that these large masses contain even smaller amounts of the red metal than the ores which must be brought from greater depths. But leanness has been compensated for by closeness to the surface, and large amounts of low-grade ore are mined to-day by steam-shovels and full-sized steam-locomotives and railway-cars in the open sunshine instead of by pick and shovel and dinky railroad equip-

Courtesy American Institute of Mining and Metallurgical Engineers

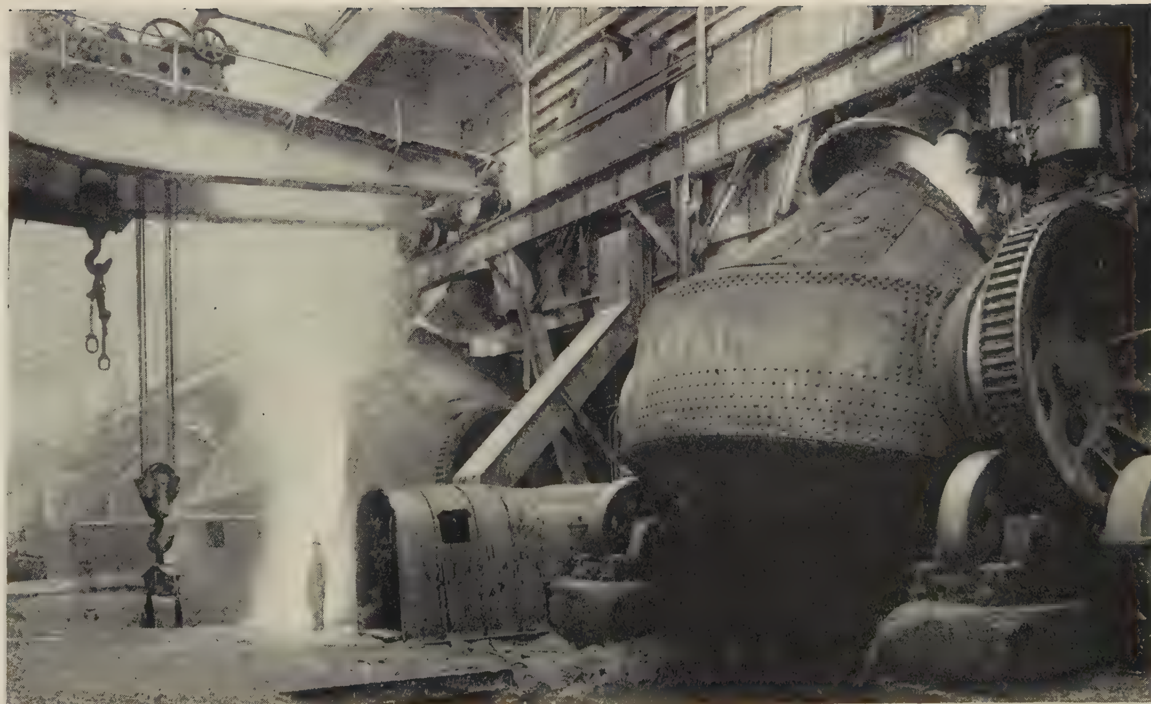
AN ELECTRIC "MULE"

Deep underground in a Butte mine. This storage battery locomotive runs on a track 18 inches wide.

Courtesy American Institute of Mining and Metallurgical Engineers

LOOKING DOWN THE SHAFT OF ONE OF THE BUTTE MINES

All of the timbering has been given a coat of cement mortar as a protection against fire and decay.



THE IMMENSE CONVERTERS AT THE ANACONDA REDUCTION WORKS AT ANACONDA, MONTANA

Here the molten matte is converted into metallic copper.

ment in underground darkness. When some of these large deposits now worked by open cut methods were first opened, underground mining was practiced. It soon became apparent that even though a large amount of worthless overburden would have to be removed it would be more economical to mine from the surface on a large scale. Notable examples of open cut copper mining are the immense deposits at Bingham, Utah, from which the largest tonnage of ore in the world is obtained, the Rio Tinto mines of Spain, and the Chuquicamata deposits in Chile. Open cut methods are also used in some fields in Nevada, Arizona and New Mexico. By mining with a steam-shovel at the surface slow and tedious excavating is avoided, little or no timber is required, pumping, ventilating, and hoisting troubles are virtually unknown, and the miners are able to work under as pleasant conditions as are experienced by the crew excavating the foundations for a sky-scraper.

It is peculiarly fitting that copper as a metal does its share in releasing more copper from the ground. After the blasting-holes are drilled a copper cap sets off the explosive that breaks the ore. Copper wires carry the current to electrically driven pumps lined with bronze to prevent corrosion by the acid mine waters, and wherever electricity for power or signal is used in the mine there copper must be.

At the surface of the extensive underground mines or near-by the hills of copper that are being leveled, the companies operating the mines have built small cities in which the concentrating, smelting, and in some cases refining and manufacturing of the copper are

carried on. With the exception of the Lake Superior region all of the large copper camps are located at long distances from the densely populated parts of the country and are isolated from other large communities. For this reason the companies have also had to build and maintain in many cases the residential sections of the communities dependent upon the copper industry. Although the miner may refer to the vicinity of the diggings in which he works as a camp, he uses this term in memory of the pioneers who established the industry. The copper camps of to-day are modern cities comparable in many respects with communities which have happier natural surroundings and closer contacts with the large centers of culture.

What would Agricola, author of one of the ealiest mining treatises, published in 1550, say if he could see a modern copper mine? How astonished an Indian of pre-Columbian days would be if he could be brought to the present-day scenes of his primitive copper mining. How impressed and awed he would be if a large engine should drop him a mile and a half on the angle at the rate of several thousand feet a minute, into the depths of a large Keweenaw copper mine. Despite our tendency to smile when we look at Agricola's woodcut showing a miner descending into a mine through the simple expedient of "sitting on the dirt," we should remember that even in those times the fundamentals of mining were not new and that it was six thousand or more years ago that unnamed Egyptian engineers or their predecessors initiated some of the methods that are systematically applied on a modern extensive scale to-day.

From a woodcut in Agricola's "De Re Metallica," published 1550

SIXTEENTH-CENTURY METHODS OF DESCENDING INTO A MINE

A. Descending into the shaft by ladders. B. By sitting on a stick. C. By sitting on the dirt. D. Descending by steps cut in the rock.

CHAPTER V

FROM EARTH TO INGOTS

As soon as a modern chunk of copper ore has gone through the racking trials of being mined and brought to daylight, it finds itself running the gauntlet of water, fire, and electricity because of man's effort to separate the copper from the gangue with which it has been associated in the lower regions. It finds extensive plants and machinery concentrated upon the work of reducing to copper thousands of tons of ore in the least possible time at the least possible expense.

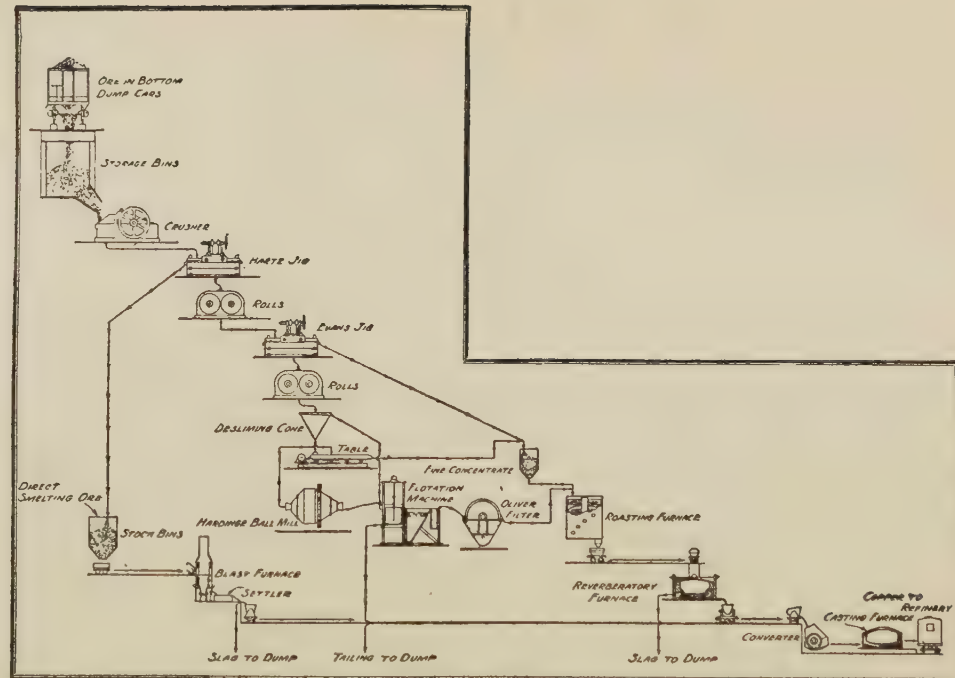
After the piece of ore has been disturbed by a blast in the underground stope thousands of feet below, it may seem to have been selected because of its richness, for transportation to the upper regions. But when it rattles down into a great ore-bin along with tons of similar chunks, it turns out not to be so exclusive. As the concentrating process goes on, and the ore is crushed, jigged, slimed, roasted, converted, fused, and thoroughly intermingled with other copper, its last suggestion of individuality must vanish.

While the first step in man's isolation of copper from its ores is taken in the underground excavations in the mine when the rocks containing ore are separated from those that do not, it is not until after the ore is brought to the surface that the systematic process of elimination of waste matter begins.

Physical methods of separating members of the copper mineral family from the associated rocks are used in initial steps. Water acts as the medium in which these separations are performed. After a large amount of barren material containing no copper has been culled out, fire is called upon to disunite the copper and whatever elements it may have been associated with. This is rather a complicated process, and in the end copper reaches a high degree of refinement. The copper that is to enter the electrical field must be purer than that which is to be used for rougher work, and for this reason much copper undergoes electro-deposition to cleanse it of all but the most minute amount of contamination. Man has found that such extreme purity is desirable for copper that is to be put to all sorts of uses, and he now requires or prefers it in the case of much copper not used electrically.

If you are interested in just how this is done, let us follow the various courses that a piece of copper may take in traveling from earth to ingot through the large Anaconda reduction and refining works in the Butte district. We shall take side-trips to other plants and compare their methods, with an occasional glimpse of the past.

As the ore comes from the mines and enters the storage-bins it usually ranges from about a foot and a half in diameter to fine dust. Before it can be put through the mechanical processes that will separate the rich from the poor or barren ore it passes through large crushers similar to those that may be seen at any rock-quarry. These smash the large pieces into smaller ones. Before and after passing through this



Courtesy Anaconda Copper Mining Company

HOW THE COPPER-BEARING MATERIAL FLOWS FROM ORE-CARS TO CARS THAT CARRY BLISTER COPPER TO THE REFINERY

This diagram shows the steps in copper ore reduction taken at the Anaconda Reduction Works

reducing process, the stream of ore passes over screens that segregate all pieces between certain sizes and collect them for a journey on the road to refined copper. A two-inch piece is the largest that is allowed to start through the concentration process; the smallest is the finest dust.

The success of the first part of the concentration process depends upon the fact that the minerals containing copper weigh more for a given volume than those that do not. You have read how in the early days gold miners panned the gravels of the river bed and won their wealth by this simple means. Gold-bearing gravels placed in a tin basin somewhat like that in common use to-day were swished about in a peculiar way in water so that the heavier gold settled at the bottom and the lighter quartz flowed over the brim. The extensive jigs and concentrating-tables at the Anaconda works use exactly the same principle in separating the copper ore and gangue, despite the fact that the peculiar knack of panning is standardized. Because the difference in specific gravity of the copper minerals and their gangue is much less than the difference between gold and the quartz gravels, copper concentration must be more finely adjusted; as the reward for concentrating a given amount of copper ore is far less than was achieved by lucky forty-niners in working over the same amount of gravel, copper concentrating must be done on a vaster scale.

The Hartz jig is the machine that accomplishes the first separation of heavy copper-rich material from the light and more barren rock. Into a formidable battery of these jigs, the crushed ore, ranging in size

between two inches and three-eighths of an inch, is fed with water. In each jig a plunger produces rapid upward pulsations of water through the bed of mineral and allows the heavy valuable pieces to settle to the bottom, while the less rich ore stays on top. The layer of lower ore, or concentrate, passes out of the lower end of the jig through a slot discharge, while the lighter material flows over the end. The particles of ore that are selected in this way escape the rest of the concentrating process and immediately enter the stage of fire. This concentrate is rich enough to be sent directly to the blast-furnace for smelting, but the rejected material, called "middling," passes through rollers that crush it still finer and enters the Evans jig, a machine similar to the Hartz jig, adapted to handle ore from three-eighths to one-sixteenth of an inch in size. In this machine a separation between rich and lean ore is again made by very similar processes, and in this case the concentrate is sent to the bins that feed the roasting furnace. The middlings pass through another crushing experience in a battery of rollers that make them still finer and prepare them for the Wilfley tables. To the output of these rollers there is added the part of the original ore that was finer than one-sixteenth of an inch. Included in this combination there is a large amount of extremely fine dust that makes "slime" when it is added to water. Ore slime is not green like the slime of ditches; it is nothing more than very finely divided ore, too fine to be affected by the concentrating-tables. To separate it from the coarser material a cone-like apparatus is used, and the slime that issues from the top is sent

directly to the flotation process. From the bottom of the de-sliming cone the coarser material goes to the Wilfley tables, which do this work because of the difference in specific gravity of the ores, but use a different sort of dance from that practised by the Hartz jigs. The Wilfley tables move a thin bed of ore forward as the result of a peculiar jerk imparted by the driving-mechanism, but the concentrate moves with greater momentum than the middling because of its greater weight to a given volume. The shaking action slightly loosens the bed of ore so that the concentrate settles below the middling. The wash water, flowing across the table at right angles to the direction of the jerking motion, carries the middling over the lower edge of the table while riffles guide the concentrate to the end of the table. The rich concentrate from the tables is added to the supply for the roasting-furnaces.

The ore rejected by the tables is sent to large revolving Hardinge mills in which many balls pound it into a powder about as fine as cement. The finely divided ore is now ready to enter upon its final step in the wet concentrating process, that of flotation.

Since early times advantage has been taken of difference in specific gravity in crude concentrating processes. The miners of Agricola's time crushed their ore in stamp-mills and then built primitive concentrators consisting of riffles that caught and held the heavier particles of the ore as it was washed down a sluice. A very similar apparatus is used in gold mining to-day. But in precise application, efficient system, and vast scale, the concentrating methods and plant of to-day are a true modern development and are

From Agricola's "De Re Metallica," 1550

ROASTING COPPER MATTE

A, B. Two furnaces. C. Tap-holes of furnaces. D. Forehearths. E. Their tap-holes. F. Dipping-pots. G. At the one furnace stands the smelter carrying a wicker basket full of charcoal. At the other furnace stands a smelter who with the third hooked bar breaks away the material which has frozen the tap-hole of the furnace. H. Hooked bar. I. Heap of charcoal. K. Barrow on which is a box made of wicker work in which the coals are measured. L. Iron spade

as far removed from the sixteenth century concentrating process as the "sitting on the earth" method of descent is from the large mine-shaft hoisting-engines of to-day.

But the concentrating process that has made possible the development of low-grade copper deposits on a large scale depends upon the fact that fine particles of heavy copper ore can be made to float while the lighter pieces sink. A woman invented this seemingly paradoxical process of flotation. Several stories have been told about the discovery of the basic principles of the process. One is that the wife of a miner discovered while washing overalls that copper grains in the dust and dirt on the garment rose to the top of soap-bubbles.

Until a short time ago the accepted story of the invention ran somewhat as follows: Miss Carrie J. Everson, a school-teacher in Denver who had an assayer for a brother, one day washed some greasy sacks in which samples had been sent to him. Customary violent agitation of the water incident to washing very dirty fabrics caused sulphide particles of ore, coated with grease from the bags, to float as a scum. Following up this occurrence, Miss Everson discovered that acid, added in small quantity to the pulverized ore, greatly increased the selective action of the oil, and that the oiled mineral could be separated from the gangue by thorough agitation of the mass and by allowing the sulphides to float as a scum, while the gangue escaped at the bottom of the vessel.

But both of these interesting stories are incorrect, despite the fact that a woman really was the dis-

coverer and her last name was Everson. More romantic than the fiction is the true story. Carrie Jane Billings married William Knight Everson, a physician of Chicago. He prospered, but was unlucky enough about 1878 to sink a large sum of money in a notorious mining promotion. Mrs. Everson had been interested in chemistry and, hoping to be able to retrieve some of the ill-fated investment, she studied mineralogy. During the absence of Dr. Everson in Mexico on a trip for his health, Mrs. Everson discovered the "chemical affinity of oils and fatty substances for mineral particles." On her husband's return he aided in the research, and on August 4, 1886, Mrs. Everson was granted a patent on the process. Dr. Everson's health failed, and he died in 1889 after the family had moved to Denver on his account. Though his widow could not commercialize her patent, and though she had to become a professional nurse in order to support herself and her young son, she continued her investigations. Charles B. Hebron, a chemist, joined her in this work and secured some financial backing, and another patent was secured jointly; but this venture was not successful. Later her son, John L. Everson, with Thomas F. Criley, developed the process on a large scale at an old stamp-mill in Colorado and at other places. But even these extensive demonstrations did not win financial reward and practical use, and Mrs. Everson in 1909 went to California with her son. Here she lived, forgotten by mining and metallurgical men, while lawsuits involving millions of dollars were fought through the courts by later claimants to the discovery of the process. Not until 1915, after she had died, after fire

had destroyed her cottage and the reports of her investigations, and after her patents had lapsed, was she traced to California and recognized as the pioneer who, too early, discovered and proved a process now used in plants costing millions of dollars.

At the Anaconda reduction works the sand and slime discarded by the earlier concentrating apparatus are relieved of their tiny particles of rich ore by Mrs. Everson's process applied on a scale so extensive that, were she able to see it, it would astonish her. The slime from the de-sliming cone through which the ore passed before it reached the Wilfley tables is mixed with middling finely ground in the large ball-mills. When this combination flows into the flotation machine, it is mixed with a surprisingly small amount of certain kinds of oil, and then the whole is beaten into a froth by vigorous agitation. The metallic mineral particles have the lucky faculty of being able to stick to the oil, while the non-metallic minerals cannot. The millions of bubbles of the froth act as tiny balloons, and when the process of stirring up and aërating has been continued for a time each air-ballon is ready to carry off a minute particle of valuable sulphide ore. Though each one may not succeed in doing so, enough rich ore is captured by the froth to make the process 95 per cent. efficient. The partiality of the froth is aided by the addition of small quantities of sulphuric acid. If the ore is ground to the almost impalpable condition of very fine clay it gives the best results. Flotation is a process in which the little particle fares best, as grains of ore as large as three one-thousandths of an inch in diameter give unsatisfactory results unless they are

mixed with much finer slimed ore. The flotation machines are the first in the process that finally condemns a portion of the ore to the waste pile. The particles of ore that are not chosen by the froth are too poor for further use, and they are called tailings and are carried to the dump, while the portion of the ore concentrated by the froth travels toward the roasting-furnaces.

After the water has done its share in carrying the ore through the various concentrating processes, it becomes troublesome instead of useful and must be got rid of. By passing the concentrate from the jigs or tables over stationary screens or into large settling-tanks the excess water in the coarse and medium sizes of concentrate are eliminated. The fluffy mass of froth containing the concentrate from the flotation machine is still four tenths water after it has been allowed to settle in tanks. Then continuous filters, which are large revolving cylinders operating in steel tanks, are used to reduce the water content to only about one seventh.

Only one third of the ore that entered the crushers at the beginning of the concentration is present and accounted for at the end either as roasting or blast-furnace concentrate. To the flotation process credit must be given for a large share of the good record in the amount of copper saved from the ore, although the very fine grinding of the ball-mills is needed to release the copper so that the flotation machines can separate it. Earlier than the introduction of flotation and fine grinding the amount of copper recovered was much lower than now, as former methods for

concentrating the very fine sizes were much less efficient than flotation, and relatively coarse rich material was often sent to the dump.

When wet methods have done their best the copper minerals, while more closely compacted, are not any closer to pure copper from a chemical point of view than they were in the ore. Fire is called upon to do its part in divorcing sulphur and the other elements from copper. Most of the copper ore mined in the world, as we have already seen, consists of sulphides of copper, and the oxides and sulphides combined comprise about nine tenths of the world total. For this reason the separation of sulphur from copper is the most important objective in the pyro- or fire-metallurgy of copper. Usually it takes three steps to do this: First, part of the sulphur is driven off, resulting in partly oxidized ore; second, the gangue minerals and more of the sulphur are eliminated; and then the rest of the sulphur is oxidized, leaving crude copper. The first step is called roasting; smelting is the term applied either to the second step or to the first two steps combined. The final step is usually accomplished by the process called converting.

If very rich chunks of ore are being treated, such as those that were separated out early in the concentrating process, the blast-furnace that performs the first two steps at one time is usually used. But if the fine concentrates from the tables and flotation machines are to be treated, roasting and then smelting in reverberatory furnaces produces the combination of copper, iron, and sulphur called matte. Roasting and reverberatory smelting are the more modern and

more frequently practised methods, because the lean ores worked to-day produce fine concentrates and the reverberatory method proves more feasible and economical under these conditions.

To roast a copper sulphide ore, it is heated. Some of the sulphur atoms united with the copper in the ore have a greater affinity for oxygen atoms under these circumstances and run off with them. Most of the copper is left alone. The iron sulphide usually mixed with the copper ore loses its sulphur but takes up with oxygen and is thus prepared to go off in the slag later on. The sulphur-oxygen combination forms sulphur dioxide, the noxious gas that you often smell when you light a match or when the coal fire smokes. It is the very same stuff that a volcano or a sulphur candle gives off. Despite its smell and the damage it does to vegetation, it is a valuable substance that can be made into sulphuric acid, the fundamental chemical whose consumption, because of its variety of uses, measures the civilization of a country.

Roasting copper ore is very similar to burning lime; in fact, the two processes are so similar that the roasted ore is "calcine," a word derived from the Latin name for lime. How early in history the roasting of sulphide ores before smelting was practised is uncertain, although in the old Roman workings at Rio Tinto, Spain, there is some evidence of roasting the sulphide ores mined there. Certainly the step from lime burning to copper ore roasting would seem to be a simple one. But despite the fact that the ancients understood lime burning, and calcined several other salts to purify them or to render them more

caustic, nowhere in the remains of the old works or in their literature is there anything from which satisfactory details of sulphide ore roasting can be obtained. Not until shortly before Agricola's time, in the middle of the sixteenth century, is there a specific account of the roasting of copper ore, and in England

From Agricola's "De Re Metallica," 1550

SMELTING COPPER ORE

A. Cakes. B. Bundles of fagots. C. Furnaces.

such treatment did not come into use until after Agricola. An insight into the methods of those times is given in a report of the "Doeings of Jochim Ganse"—an imported German—at the "Mynes by Keswicke in Cumberland, A. D. 1581," wherein the delinquencies of the then current practice are described: "Thei never coulde, nether yet can make copper under XXII tymes passinge thro the fire, and XXII weekes doeing

thereof and sometyme more. But now the nature of these IX hurtfull humors abovesaid being discovered and opened by Jochim's way of doeing, we can, by his order of workeing, so correct them, that parte of them beinge by nature hurtfull to the copper in wasteinge of its, ar by arte maide freindes, and be not onely an encrease to the copper, but further it in smeltinge; and the rest of the other evil humors shalbe so corrected and their humors so taken from them, that by once rosteinge and once smeltinge the ure (which shalbe done in the space of three dayes), the same copper ure shall yeeld us black copper." Jochim proposed by "rostunge" to be rid of "sulphur, arsineque, and antimony."

Through the accidental firing of a pile of sulphide material roasting was probably discovered. Even today in some parts of the world this roasting in heaps is practised, just as the burning of lime is sometimes done in a similar crude fashion. Though primitive, heap roasting requires skill and judgment, as the process aims at the removal of only a portion of the sulphur. Over- and under-burning must be avoided. Some of the heaps made are of large size, and one described is forty feet long, twenty-four feet wide, and six feet high, containing about 240 tons, burning for seventy days. At Mansfeld, Germany, roasting of copper ore is practised to remove not sulphur but bituminous matter, which is undesirable. An improvement over heap roasting is the use of stalls or rectangular brick chambers in which to carry on the operation, but, aside from the opportunity of draft regulation and control of the burning, it is little superior

to heap roasting. To-day, just as machines are doing the work of many other cruder and earlier processes, copper ore roasting is accomplished in furnaces into and out of which the ore flows continuously. In the Anaconda reduction works, cylindrical furnaces of the McDougall type with several hearths, one above the other, substantially built of brick and inclosed in a steel plate casing, are used for this process. The concentrate is automatically fed to the top hearth, from which it begins a journey downward. Two large plow-like arms attached to a shaft in the center of the furnace move the concentrate from the circumference to the center of the hearth, where it drops through an opening to the next hearth. Two similar arms here pick the ore up and conduct it to the circumference for a repetition of the cycle on the lower hearths. Hot gases come up from the lower hearths, where concentrate introduced earlier is roasting in its own heat. This ability of the concentrate to roast itself is due to the large percentage of iron pyrite that it contains. Only when a furnace is being put into operation is there need of outside heat from coal or wood. The rabble arms stir the concentrate on its downward path from hearth to hearth, exposing fresh surfaces of the charge to the hot gases, and they would warp if they were not protected by a continuous circulation of water on their interiors. When the ore passes from the bottom of the roasting furnace it contains only 8 or 9 per cent. of sulphur instead of the 30 to 33 per cent. that it had when it entered.

The success of the next operation, smelting, depends upon copper's affinity for its earlier associate,

sulphur. The roasted ore consists of a mixture of sulphides of copper and iron, iron oxide, and metallic copper, together with silica and alumina which have been purposely left in the ore during concentration because of their aid in the smelting process. Lime, which will aid in forming a more fusible slag, is also present, as it has been added to the ore during the roasting process. This mixture is charged upon the hearth of the reverberatory smelter and bombarded by heat radiated from the countless particles of incandescent carbon in the coal-dust flame. The result is the formation of matte, slag, and the gases that are given off. In the matte the copper and a large part of the sulphur are contained, while the slag is made up of the iron, silica, alumina, and lime. The rather complex reactions are brought about simply by the addition of heat to the charge; no complications are introduced by the addition of fuel or blasts of air as in the blast-furnace. When melted, copper has greater affinity for sulphur than have the other metals, and for this reason during the smelting the copper oxide of the charge relieves the iron sulphide of its sulphur and gives it its oxygen. As the copper does not need as much sulphur as the iron, sulphur dioxide gas is also formed. In all, up the flue goes more than a quarter of the sulphur in the smelting mixture. The iron oxide becomes part of the slag, and the copper sulphide with the remaining iron sulphide combine to form the matte. As a result, the matte, being heavier, settles to the bottom, while the slag floats on top. A sudden drop into a stream of cold water is the fate of the slag as it flows continually out of the furnace;

after this cool treatment it is sent to the dump. Whenever enough of the precious matte accumulates, the bottom of the furnace is tapped and the liquid taken in large steel ladles to the converter. The smelting process results in a further richness of copper; the matte contains 38 per cent. of the red metal as contrasted with the roasted ore, which contained only 9 per cent. From each hundred tons of charge, sixty-seven tons of slag and twenty-four tons of matte are produced. Reverberatory furnaces have grown with the copper industry; the modern reverberatory furnaces have hearths twenty feet wide and 143 feet long, sixteen times the area of the Anaconda furnaces constructed in 1884. Since that early day not only has the size of the furnaces increased but the methods of charging and firing the furnaces have been improved. Where automatic conveyors now feed the furnaces, men once had to brave poisonous sulphur fumes during hand feeding; instead of being heated from grate fires, powdered coal sprayed directly upon the hearth produces the temperature needed.

Let us return to the coarse, rich ore that we left shortly after the beginning of the reduction process, and see how it is turned into matte. The ore is smelted in blast-furnaces, steel structures about fifteen feet deep, only about five feet wide, but in length ten to fifteen times their width. To protect them against the intense interior heat, the walls are jacketed, and a constant stream of water reduces the temperature that otherwise might cause disaster. Into these furnaces the coarse ore, broken limestone rock, and a small quantity of coke are introduced. When the charge

is ignited and blasts of air supplied by great rotary blowers are forced into the bottom through numerous tuyere pipes, the coke burns, together with three fifths of the sulphur in the ore, and the combined heat brings about reactions very similar to those in the reverberatory furnace. Matte and slag are formed, and those two products collect in a shallow pool in the bottom of the furnace and flow out through water-jacketed spouts into large settlers. In this large vat the matte separates to the bottom just as it did in the reverberatory furnace, and the slag passes through an over-flow-spout on its way to the waste heap. Smelting can be carried on without the aid of any fuel other than the sulphur contained in the copper-bearing iron pyrites of the ore if the ore is sufficiently rich in pyrites, and when this is the condition the process is called "pyritic" smelting.

Although the blast-furnace may produce matte in one operation while both the roasting furnace and the reverberatory furnace are necessary in the process usually used now, it does this because it combines the functions of both roasting and smelting. It oxidizes and smelts simultaneously, and also uses the heat generated by the oxidation of the sulphur and iron. The blast-furnace shaft can be roughly divided into two zones, the preheating and the fusion zones. In the first the silica remains unaltered; the chalcopyrite has one fourth of its sulphur driven off as vaporized sulphur and becomes a different mixture of copper and iron sulphides; and the pyrite, which is the iron sulphide mixed with the copper ore, loses about half of its sulphur and becomes an iron sulphide con-

taining less sulphur. In the lower zone the chalcopyrite mixture melts as soon as its temperature becomes high enough; the sulphur remaining in the pyrite is partly burned to sulphur dioxide by the oxygen in the air-blast; and the rest of the sulphur joins the iron and copper to form matte. Thus it may be seen that the blast and reverberatory methods, which may seem to be different if you see both of them in operation, are very much alike so far as their chemistry and physics are concerned. When a mine produces partly oxide and partly sulphide ore, the oxide ore can be mixed with the sulphide to produce the effect of roasting without the trouble, and the roasting step necessary with all-sulphide ore can be abandoned.

Fuel economy is partly responsible for the more prevalent use of the reverberatory furnace in preference to the blast-furnace; despite the low thermal efficiency of the reverberatory furnace, ranging from 5 to 20 per cent., the utilization of the waste heat for steam-making and power production makes the reverberatory furnaces more economical in most installations. At Anaconda the blast-furnaces stand idle, and are not operated unless the ore production exceeds the capacity of the batteries of reverberatories. The size of the present-day ore particle is another cause of the decline of the blast-furnace. So long as the ore is rich and large, the blast-furnace does satisfactory work. Attempts to use the fine concentrate of the tables and flotation process in the blast-furnace are literally blasted; the powdered ore joins the gases, goes up the flue, and, unless specially taken care of, settles over the countryside. Only chunks of

ore can stand this rough treatment; the "fines" give up their copper more readily if they are subjected to the gentle treatment of the reverberatory furnace.

There is one interesting thing about both processes which may have been noticed. Unlike the conditions in the blast-furnace producing iron, the carbon of the coke or coal flame does not play anywhere near so important a part in the reactions in the copper reduction processes. This fact makes it possible to look forward to the use of some other source than coal for the heat required by the process. Tests have been made in numerous instances which show that from an operative point of view the use of the electric furnace for the production of copper matte is a success either by roasting and reverberatory methods or by the blast-furnace. Practical use of electrical methods is a matter of economic and mechanical perfection. Where coal is scarce, very soon we may expect the abandonment of use of stored-up sunshine of the Carboniferous era and the substitution of white coal that runs down to the sea hour after hour whether we use it or not.

When matte is obtained either from the reverberatory or the blast-furnace, the silica, alumina, and part of the sulphur that were in the ore have been eliminated, and the red metal desired is still united with sulphur and iron. Spectacular methods are used to separate the copper from the sulphur and iron, which are literally burned out.

Into a large pot-like furnace about sixty-five tons of molten matte are poured. Through pipes entering the bottom of the furnace compressed air under moderate

pressure is introduced. Varicolored flames belch forth from the mouth of the converter, as the furnace is called, and the sulphur and the iron are burned. Sulphur dioxide goes up the flue, and the iron oxide left joins with the raw ore containing silica and alumina that have been introduced into the converter with the matte so that iron slag can be formed. During this first part of the process the copper content has been increased from the 45 to 50 per cent. in the matte to about 78 per cent. When the slag has been poured off by tilting the whole converting furnace, the blowing is continued until virtually all the sulphur is burned off, and the metallic copper, freed at last from bondage with other elements, sinks to the bottom of the furnace, carrying alloyed with it silver, gold, and various other valuable or troublesome metals. It takes about five hours for a converter to change matte into copper. The experienced eye of the operator determines when the different stages of the process arrive at completion. The size and color of the flame varies; the color changes from yellow, through orange and red, to blue. Another sign that the converter foreman watches is the way in which small particles of slag, matte, or copper, thrown up by the air-blast, act when they strike the hood at the lower end of the flue into which the converter gases pass.

An Anaconda converter complete weighs about three hundred tons, it must be able to tilt quickly and accurately and elevate tons of molten metal with as much ease as a foundryman pouring brass to make a small casting. Two pairs of massive steel rollers carried on substantial foundations support the converter, and

a large electric motor provides the power for its movements. On its inside, the steel shell is thickly lined with magnesite brick. Though you would not realize it from looking at it, this basic lining is now saving much money wasted by use of the acid linings of a few years ago. Before the magnesite lining was perfected, the lining was also a part of the charge. Ore, high in the acid-minerals silica and alumina, was ground together with some of the clay-like slime of the mechanical concentration process and tamped into the shell for lining. Each charge of matte, in being converted, used a large layer of this lining as the iron of the matte united with the silica and alumina to form slag. After two or three blows the whole process of lining had to be repeated. Now, in addition to a lining that will not enter into the converting, layers of magnetite, a combination of iron oxides, and a further skin of alumina are formed upon the magnesite, by the slag, and theoretically the lining lasts forever. In practice, of course, the wash of the molten materials in the converter gradually wears it away, and if, because of accident or lack of matte to be treated, the converter must be allowed to cool down, some of the lining will be flaked off by contraction.

The slag produced in the converter, unlike that from the reverberatory and blast-furnaces, is too rich in copper to be sent to the dump, and its metal is saved by treatment in the blast or reverberatory smelting furnace. The copper while still molten is sent to the refining furnaces, built on the reverberatory plan, where remaining small amounts of iron, sulphur, and

slag are removed. In imitation of the converters, compressed air not only assists this iron and sulphur to enter the slag but the blast also oxidizes some of the copper into cuprous oxide. This oxide mostly melts and diffuses through the metallic copper, and, readily parting with its oxygen to the impurities, further facilitates their complete oxidation. When the blast has virtually eliminated the impurities, the molten metal contains a great deal of dissolved oxides which must be reduced. Ends of green tree-trunks or poles are forced under the surface of the molten charge, and the large quantity of gases generated by the dry distillation of the poles reduces the oxide and brings the copper to a high degree of uncombined purity. At this point the copper still contains the valuable metals and also impurities that prevent its use for electrical purposes. It is run into molds and turned into "anodes" weighing about five hundred pounds. These large thick sheets of copper leave for the electrolytic refinery where more experiences await them.

Only since 1878 has the converter been used, and to-day in many places the old method is practised of roasting the matte and then smelting and refining the oxidized product by repeated fusions. In the cruder and earlier processes the basic reactions and methods do not differ greatly from modern practices, though much more work and an inferior product are the penalty attached to the less advanced methods. Before the Christian era the refining of copper by repeated fusion was practised, and by Agricola's time

roasting of matte and the subsequent refining of the oxidized copper were the usual methods of obtaining metallic copper.

When we compare the immense mines of to-day with the pits of yesterday, modern furnaces with the crude contrivances of the past, nothing is more striking than a comparison of the speed of the reduction processes. When ore had to be heap-roasted and the matte repeatedly roasted in stalls, it took four months to achieve copper. Now sulphide ore can be fed into the blast-furnace in the morning, the matte sent directly to the converter, blown into copper, and shipped as anodes in the evening.

But valuable by-products as well as time are saved in modern reduction works. Formerly sulphur fumes and gases were poured forth into the air to poison the vegetation and the surrounding country; now Cottrell precipitators electrify the smallest particles of fume and save them to be turned into valuable, civilization-producing sulphuric acid. The dust that escapes from the furnaces are caught by the precipitators, or large settling-chambers, and the heat that formerly went into the air is now used to run engines or warm buildings.

We have traveled through the reduction processes at Anaconda, and have seen how a piece of sulphide copper ore might be treated in other places and at other times. Because a copper oxide ore is virtually the same as a sulphide ore that has been given a thorough roasting, and because oxide and sulphide ores are often treated together, we also know the experiences that oxide ore must endure to become metallic. There

is another way in which copper ore can escape the bondage of the earth and become metal, and that is by the wet process. Much low-grade ore is exploited by using this comparatively modern method. But let us first see how uncombined metallic native copper is prepared for man's use.

Compared with the processes that a sulphide ore must pass through, the native copper ores of Michigan undergo a very simple process to become usable copper. One to 3 per cent. copper with some native silver are contained in the conglomerate and amygdaloid ores. These ores go through a concentration similar to the first steps that sulphide ores take. Crushers, steam stamp-mills, and Hardinge mills crush them, and then they dance on jigs and tables until a coarse concentrate containing about 60 per cent. copper is produced. This rich concentrate, joined by the lumps of mass copper that are often found in the Michigan mines, is charged into a reverberatory furnace and simply melted down without any fluxes; the slag is skimmed off as it is formed. In some cases the molten copper is sent to another furnace for refining, but often it is purified in the same furnace. The impurities in this native copper are removed by oxidation and reduction and by contact with fresh wood similarly to the copper from the converters. After this fire refining, the copper is cast into commercial shapes for marketing; only that portion high in silver content achieves the distinction of being sent through electrolytic refineries. The best "Lake" copper, as the copper made from Michigan ores is called, is usually so pure that it compares favorably with

electrolytically purified copper and it is suitable for use for electrical work.

One general method of extracting copper from its ores depends upon the solubility of copper in dilute acids when it is combined with other elements. Water, acids, iron, and electricity, instead of heat, are the reagents that secure the separation; the processes are carried out in large tanks instead of immense furnaces. Extraction of copper by the wet method is usually accomplished in three steps: First, the copper if necessary is converted into a soluble form; second, the soluble copper salt is dissolved out and taken into solution; third, the copper is precipitated from the solution as the metal.

A story is told at Butte of how one of the simplest and most important of the wet processes of copper recovery originated. The waste water from one of the mines flowed through "Jim" Ledfad's back yard. One day he threw some tin cans in the little gully made by the mine water, and the next morning he was surprised to find that they had turned to a slush of copper. An assay showed that the metal was 98 per cent. pure. Jim kept his secret well and signed up a year's contract for all the water that came from the mines. Before his twelve months of opportunity were up, he had made ninety thousand dollars out of his discovery.

Jim's process is used at Butte to-day and at virtually every other sulphide copper mine in the world where waters have a chance to flow. The sulphide ores are acted upon by the oxygen in the air and in the water and are changed to copper sulphate. This com-

pound is easily soluble in water and runs off or is pumped out of the mine in the troublesome water. If this water comes into contact with iron, such as is contained in scrap tin cans, the sulphate radical, because of its chemical affinity, drops the copper, leaving it as such, and unites with the iron. This exchange occurs because iron is more positive than copper in the electro-chemical series. When copper and iron are brought together there is an electrifying time, a real current is set up, but the direction of the current and the result of the precipitate encounter over the sulphate is predestined by the properties of the two metals. In this case, though iron wins the sulphate, copper is released to do its work in the world as a free metal. At the Copper Queen mine at Bisbee, Arizona, as well as at the Butte mines, special plants have been installed to recover the copper in the mine water. The precipitation of copper upon iron in this way is known as "cementation," and the product is called "cement" copper. Despite the large number of scrap tin cans produced as a by-product of civilization, the supply is not large enough for this use. Scrap iron is used where it can be obtained, but crude pig-iron is the standard source of the metal used to precipitate copper.

At Rio Tinto, Spain, there are about twenty-five million tons of copper sulphide ore that are waiting for the weather to change their copper into the form that can be dissolved and precipitated by iron. These ores consist of massive pyrites containing about 3 per cent. copper. The ore is built into massive heaps of a million tons or more, arranged with suitable venti-

lating flues and chimneys, and it is sprayed with water to promote the atmospheric oxidation of the pyrites. By an interaction of the iron sulphates formed with the copper sulphides, soluble copper sulphate is finally obtained and leaches out. Ferrous sulphate is first formed, which slowly oxidizes to ferric sulphate and reacts with the cuprous sulphide to form soluble copper sulphate and insoluble cupric sulphide. The latter is again oxidized to cupric sulphate by the ferric sulphate and the atmospheric oxygen. The solution draining from the heap contains both ferric and cupric sulphates, and this iron sulphate is reduced to the ferrous sulphate by passage through a layer of fresh ore, thus preventing unnecessary waste of the iron used in precipitating the copper from the cupric sulphate solution. It takes a period of four years to complete the process of extraction of a heap of ore.

Before the flotation process was adopted at Butte, tailings containing thirteen pounds of copper to the ton, three times as much as is contained in the tailings produced now, were sent to the dump. Now this "waste" is re-mined and the copper is extracted by leaching. The spectacle of one generation prizing what the past has thrown away is too frequent to be odd. Even Agricola, who in the fifteen hundreds wrote the first detailed work on metallurgy, tells of men who made an independent business of working over the tailings of mine dumps. Now some of the dumps created only a few years ago are looked upon by the operators in the same way that a coal-hunting pickaninny regards the ash-pile of a careless engine-tender. They are in the same class with the mines

themselves. Many Michigan mines are reworking at a profit their tailings of the past, and, as metallurgical processes improve and smaller and smaller amounts of copper can be profitably extracted, every dump will become available for exploitation as a new copper mine.

Water containing a small amount of lime carbonate has run over the Butte tailings and changed part of the sulphides to carbonates, but most of the ore has been unchanged. In the extracting process the tailings are first roasted to change copper sulphide into oxide and then placed in large lead-lined tanks, one thousand tons at a time. Seventy thousand gallons of fresh water, thirty-five tons of commercial sulphuric acid, and fifteen tons of common salt are added. This solution, heated, leaches downward through the roasted ore, and the percolation is repeated until all metal possible has been dissolved. The sulphuric acid dissolves the copper, and the main purpose of the salt is to dissolve the silver, which would not be taken up by the acid alone. The salt also increases the speed of extraction of the copper. Iron is used to precipitate the copper and silver, and as the cement copper is only 60 per cent. pure it is smelted in the reverberatory furnace.

Much the same process, without the roasting, is applied to part of the upper and oxidized ores at the copper mine at Bingham, Utah. Sulphuric acid is the most frequently used solvent in hydrometallurgical processes, and in some cases the ore itself produces the acid that leaches it. If a sulphide ore is roasted preliminary to leaching, the sulphur dioxide can be

saved and converted into sulphuric acid. Though most of the copper of the world is locked up with sulphur, this element seems perfectly willing to aid man in obtaining the red metal. In smelting, sulphur often furnishes virtually all the heat; in leaching, it makes the acid that carries off the copper.

Some substitute for iron in precipitating the copper from solution has been searched for. Hydrogen sulphide, the evil-smelling gas that is present in decayed food, particularly bad eggs, not only performs this function well but rejuvenates the sulphuric acid at the same time and prevents the loss of both acid and iron that occurs when the useless ferrous sulphate runs away as the result of iron precipitation of copper solutions. But this gas is difficult to produce and handle in large quantities, and the process is not used commercially.

Electricity that hauls and lifts the ore, that jigs it, that may smelt it in the future, can virtually substitute for iron in removing copper from solution. It seems probable that much of the world's copper which must be produced from lean ores will be transformed from ore to refined marketable copper in only two essential steps: solution in acid, and electrical precipitation from solution. If the ores are sulphides, they will have to have a preliminary roasting. Even the process of electrolytic refining of which we shall tell later, will be included in this tabloid process of leaching.

Such a process is now in operation at the second largest known copper deposit in the world, that at Chuquicamata, Chile. The principal mineral is an oxy-

sulphate known as bronchantite, which, though only partially soluble in water, is readily dissolved in weak sulphuric acid. Salt, sodium chloride, is also present along with some atacamite, or copper oxy-chloride. About four hundred million tons of ore have already been proved, and it averages over two per cent. copper. Steam-shovels mine the ore; then it is crushed, and sent on belt conveyors to large leaching tanks that each take a charge of ten thousand tons. Because chlorides are present in the ore, the acid leaches out cupric chloride as well as sulphate. The chloride must be removed before electrolysis; otherwise the chlorine gas would be liberated at the anodes and chances of gas attacks would be good. The cupric chloride is changed to cuprous by contact with metallic copper, and as cup rous chloride is insoluble it is filtered out. In electrolyzing the remaining sulphate solution an inert anode must be used, so that copper is carried by the electric current from the solution and deposited on the cathode. Because Chuquicamata ores are mostly sulphates, the electrolysis produces more sulphuric acid than can be used; no acid has to be imported and, like the pyritically smelted ores and roasted ores leached in their own acid, they fall thus partly into the self-reducing classification.

Application of wet reduction of copper has one serious disadvantage if the ores run high in gold or silver, as these precious metals can not be recovered by usual methods. But the leaching process is the hope of lean ores for future conversion into valuable sources of copper. Other hydrometallurgical methods will undoubtedly be devised; some that are at present

on paper or in laboratories will be applied. A combination of the flotation process of concentration with the leaching process promises to make available ore that is even leaner than that now exploited.

As copper has contributed so vitally to the development of the electrical age that we are now in, it seems only just that electricity plays such an important part in the preparation of copper for the work of the world. Because copper is used in electrical work, it must be pure; it can be made pure because it can be refined electrically.

To-day more than five sixths of the copper produced in the United States is sent through the electrolytic refining process. Blister copper from the converters, black copper from the furnaces, and even the pure Lake copper from Michigan enter the refineries and come out of the melting-pot without distinction of class, and of a single purity. First of all, copper is refined to make it pure, but there is a secondary reason that at times becomes primary. In some cases copper that has come through the fire refining processes will pay its own refining costs many times over on account of the valuable metals that it contains. Gold, silver, platinum, and palladium are concentrated in the copper and are separated during electrolysis. Millions of ounces of these metals that otherwise would be lost are recovered in this way. Some of the Lake coppers that are sufficiently pure for electrical work without refining are sent through the process only because there is enough silver in them to make it profitable. If copper contains even as little as ten dollars' worth of

precious metals to the ton, it will find a journey through the refinery worth while.

When copper enters the refinery it is melted in reverberatory furnaces and cast into anodes, if it is not already in that form. Then it is ready for electrolysis. This is a simple operation in principle, but it is carried out on a large scale. At large refineries, such as those at Perth Amboy, New Jersey, Baltimore, Maryland, or Great Falls, Montana, there are thousands of lead-lined wooden tanks in lengthy buildings, each containing two sets of copper plates immersed in blue liquid. Heavy copper bus-bars carrying electric current lead to the plates. Electrolysis consists of feeding in direct current to the impure copper positive plates, called anodes, and thus inducing the copper to purify itself by dissolving in the electrolyte of copper sulphate and sulphuric acid and then depositing on the other or negative plates, called cathodes. The cathodes are mere paper-thin sheets of copper when the process begins but they finally get thick and fat at the expense of the impure anodes. The various impurities virtually all refrain from joining with the copper on the cathode. Nickel, cobalt, iron, manganese, zinc, lead, and tin are electropositive to copper and hence dissolve at the anode and concentrate in the solution. The precious metals, gold, silver, and platinum, with selenium and tellurium, are electronegative and do not dissolve but drop down to the bottom of the tank and form what is called "anode slime." The impurities in the form of compounds of copper with oxygen, sulphur, tellurium, and selenium also form

part of the anode slime. As arsenic, antimony, and bismuth stand near copper in their electrochemical behavior, they are partly dissolved and may be deposited at the cathode. It requires about a month for an anode weighing five hundred pounds to be dissolved to such an extent that its remains are sent back to the anode casting furnace. During this time the constantly flowing current of heavy amperage but low voltage has built up three sets of cathodes each weighing about 135 pounds. To aid the action the copper sulphate electrolyte is kept in constant circulation by pumps and is maintained at a temperature near 135 degrees Fahrenheit. At intervals the electrolyte is purified and the metallic salts that it has acquired are crystallized out and refined. Most of the copper sulphate or bluestone of commerce is obtained from the electrolyte of the refineries and nearly seven tenths of 1 per cent. (7,823,000 pounds in 1920) of the domestic refined copper are used this way. The anode slime is refined and the gold and silver sent to the mint or placed on the market. Precious platinum and palladium are sold as sponge, and the selenium may go to make photo-sensitive cells. For tellurium, which is the weak sister of sulphur, the industrial world has up to the present time been able to find little use.

The cathodes are very nearly pure copper—99.98 per cent. pure. But they are not in shape so that they can be handled easily in commerce or in the wire, pipe, and sheet mills, and for this reason they must be melted. This would seem to be an easy matter, but during the fusion in the reverberatory furnace the copper tends to revert to impurity by reason of the in-

fluence of the sulphur found in the coal, as well as that of the oxygen in the air. It succeeds partly, and the melting process has also to become a fire refining, using the air-blast, poling, and other steps that the copper had experienced before its cleansing treatment with electricity. And despite all precaution it emerges from its melting less pure than it entered, though it easily surpasses non-electrolytic copper. A representative analysis of refined electrolytic copper would give results that would be approximately as follows:

Copper, 99.95000 per cent.; silver 0.00100 per cent.; gold, 0.00001 per cent.; sulphur, 0.00300 per cent.; oxygen, 0.0300 per cent.; iron, 0.0020 per cent.; nickel, 0.0015 per cent.; arsenic, 0.0015 per cent.; antimony 0.0020 per cent.; aluminum, 0.00100 per cent.; phosphorus, trace; lead, 0.00200 per cent.; bismuth, trace; selenium, 0.00050 per cent.; tellurium, 0.00050 per cent.

The molten copper of the refining furnace is cast into commercial shapes. An automatic machine pours the metal into copper molds, tips the cast copper into a cooling bath of water, and sends the bars, slabs, cakes, and billets on an endless belt to the weighing scales ready for shipment. As copper is used in many industries, the form in which it is placed on the market depends upon the use to which it is to be put. Ingots of copper are used primarily where the copper has to be remelted in crucibles either for the making of copper castings or the manufacture of alloys such as brass and bronze. They have a shape that will readily fit into crucibles, and are about ten inches long, weighing from sixteen to twenty-two pounds. Ingots have one

or two notches so that they can be broken easily in two or three pieces if necessary. Wire bars, the most popular form of refined copper, are used at mills as the material for the drawing of copper wire. These bars are cast with pointed ends in order that they may easily enter the first set of rolls. The size and weight of wire bars vary greatly, the length from thirty-nine to one hundred inches and the weight from 135 to 770 pounds. Slabs and square cakes of various sizes are used for rolling purposes, where sheet copper is the final product; and their size depends upon the size of the finished product. Circular cakes are used for the manufacture of large seamless cylindrical products such as hot water heaters and tanks. Billets are used for the manufacture of seamless copper tubing of all sizes, and during the war were used extensively in the manufacture of the smaller size of shell bands. Billets vary from three to eight inches in diameter, and from fifteen to fifty inches in length, and their weight varies from seventy-five to six hundred pounds.

A small amount of copper, mostly from Arizona, is so pure and contains so little precious metal that it may be sold for casting purposes directly after fire refining; otherwise all of America's copper, excepting that of northern Michigan passes through a dozen refineries. Half of these, the half with the largest production, are on the Atlantic tide-water, and only three, those at Great Falls, Montana, Tacoma, Washington, and Trail, Canada, are west of the Great Lakes. The Eastern refineries are not only more numerous but have greater producing capacity. The American Smelting and Refining Company refinery at Baltimore is cred-

ited with a capacity of 720,000,000 pounds of copper a year, which exceeds by more than 100,000,000 pounds the total refinery output for the whole country in 1921, an off year for copper. The Nichols Copper Company at Laurel Hill, New York, has a capacity of 500,000,000 pounds, and the Raritan Copper Works, Perth Amboy, New Jersey, controlled by the Anaconda, has a capacity of 480,000,000 pounds. Both the American Smelting and Refining Company plant at Maurer, New Jersey, leased by Phelps-Dodge, and the United States Metals Refining Company, Chrome, New Jersey, have capacities of 240,000,000 pounds, and the Great Falls, Montana, refinery of the Anaconda Copper Mining Company and the American Smelting and Refining Company at Tacoma, Washington, both have capacities of slightly more than 200,000,000 pounds a year. The electrolytic refinery of the Calumet and Hecla Mining Company at Hubbell, Michigan, is rated at 60,000,000 pounds. It is estimated that the tonnage of the fire-refined copper from the Michigan district is about one sixth of that produced by electrolytic methods. When compared with American refineries, those of other countries seem insignificant. England, Wales, New South Wales, Queensland, South Australia, and Chile each have one, while Japan has eight, Russia three, and Germany one.

The geographical distribution of the smelting and reduction plants of the country is entirely different from that of the refineries; it more nearly tallies with that of the mines. It is decidedly uneconomical to transport worthless gangue a great distance, and for this reason the concentration processes up to the point

at which metallic copper is secured must be carried out near the place where the ore is taken from the earth. It is, however, profitable to refine away from the mine. As most of the copper must travel east in order to be manufactured and as the coal for generating the electricity used in refining is also near the Atlantic coast, it is more economical to carry on the refining of a large portion of the copper on the Eastern seaboard. More than fifty copper smelting works are scattered through the mining districts of North America, and virtually every one has at least one blast-furnace or reverberatory furnace and one converter, although some of the smaller ones ship matte to the larger smelters.

About two dozen companies produce most of the copper that is refined in the United States. The control of production rests in four main groups: the companies operating in the Lake copper region in Michigan; the Anaconda group operating in Montana; the Guggenheim interests, principally the American Smelting and Refining Company; and the Phelps-Dodge group, chiefly concerned in production in Arizona. Chief among all the many producers is the Anaconda Copper Mining Company, which now owns mines, refineries, and fabricating shops. When it bought early in 1923 the Chile Copper Company, owner of the great deposits at Chuquicamata, Chile, and placed it beside the American Brass Company, the largest fabricating plant for brass and copper products, which it acquired shortly before, it became second to the United States Steel Corporation in the metal world. Incidentally, it is interesting to know

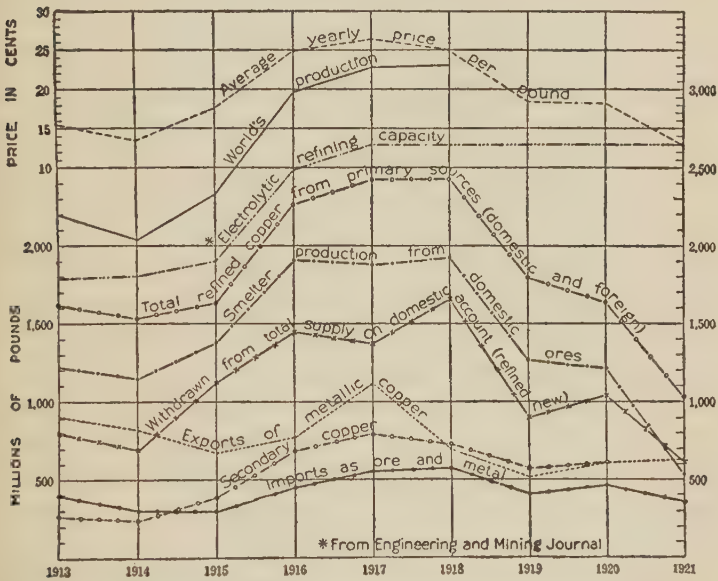
that the purchase of the Chile interests required about $75,000,000 cash and is said to rank as the largest single item of financing by a mining company that has ever been carried out in any country. Prominent among the copper producers are also the Arizona Commercial Mining Company, Braden Copper Company, Calumet and Arizona Mining Company, Calumet and Hecla Mining Company, Chino Copper Company, Copper Range Company, East Butte Copper Mining Company, Green Cananea Copper Company, Inspiration Consolidated Copper Company, Kennecott Copper Corporation, Miami Copper Company, Mother Lode Coalition Mines Company, Nevada Consolidated Copper Company, New Cornelia Copper Company, North Butte Mining Company, Old Dominion Company, Phelps-Dodge Corporation, Ray Consolidated Copper Company, Shattuck Arizona Copper Company, United Verde Extension Mining Company, Utah Copper Company, and Utah Consolidated Mining Company.

Perhaps you would like to know what is done with the metal that this extensive industry produces. Suppose we take the year 1923, which is more typical than the two succeeding years, although even it is not an altogether typical period. The total production of refined copper in the United States for 1923 is given as 2,248,000,000 pounds. Of this 1,435,000,000 is new copper produced from domestic sources, and 683,000-000 pounds is from foreign sources, although a large portion of it is refined in this country. The rest of the production is made up of secondary copper, which amounts to 130,000,000 pounds during the year. Not

only do the large refineries rejuvenate copper, brass, and other alloys that have seen one round of service but numerous small plants in all parts of the country make a business of remelting and purifying old scrap copper and alloys. About half of the secondary copper is produced from new scrap from copper and brass manufacture. In 1923 the domestic consumption of new copper is recorded as 1,305,000,000 pounds, but to this must be added the 130,000,000 pounds of available secondary copper. Imports of metallic copper are included in the figure for production from foreign sources; and we usually bring into the country about one third to one half as much metal as we consume from new domestic sources. But an amount larger than our imports is exported; it usually equals the domestic consumption of new copper, although in 1923 it only amounted to 773,000,000 pounds. In reality more copper than this is sent to other lands, as this figure includes only the unmanufactured copper exports, and the amounts in manufactured articles sent overseas is unknown. If these figures are a little difficult to follow, as figures are apt to be, the chart showing the principal features of the copper industry from 1913 through 1921 may help the reader to visualize how and where copper is used.

The cost of copper, both from the point of view of the producer and the consumer, is important because it has much to do with how much is produced, consumed, bought, and sold. It will be found that the price of copper has fluctuated with that of other staple commodities. During the war prices naturally rose when

the demand was great, but since they have fallen as low as pre-war levels or lower. During the period of America's participation in the war, copper had its price fixed by the Government, and it devoted itself almost exclusively to winning the war. Electrolytic



From "Mineral Resources, 1921"

CHART SHOWING THE PRINCIPAL FEATURES OF THE COPPER INDUSTRY, 1913–21

copper now sets the price pace for all other grades. As late as 1915 Lake copper sold at a premium of about one quarter of a cent over electrolytic due to an old belief in its superiority that originated in the days before the extensive production of electrolytic copper. Though Lake and electrolytic copper can

hardly be told apart, the tables have since been turned, with a slight premium on the electrolytic variety at times.

When the United States Geological Survey made its superpower survey to determine the feasibility of a gigantic electrical system that would supply the whole of the North Atlantic section of the country with electric power generated at the coal mines and waterfalls, it was naturally interested in the cost of copper, as the metal would be used in all of the electrical transmission systems, machinery, and wiring of this undertaking. An investigation of the cost of production of copper was made in order to obtain information for this project. It was found that during the period 1909–20 the average cost by the pound was 11.35 cents. This figure did not include a charge for the depletion of the ore, which would range from two to four cents, or for the Federal income and excess-profits taxes that were very high during that period. The figures do include the mining, milling, smelting, refining, transportation, and selling costs, general depreciation of plant and equipment charges, and all taxes except those noted. This investigation showed that it cost about four cents more to the pound to produce copper from the native copper ore in Michigan than it does to obtain it from the vein mines, such as Butte and the disseminated-ore mines such as are found in Arizona and Utah. In 1920 the average cost of copper produced in all three types of mines was 14.94 cents, while for the different types it was: vein mines, 14.2 cents; Lake mines, 18.2 cents; disseminated-

ore mines, 14.6 cents. In 1920 the average selling price of copper by the pound was 18.4 cents.

Such is the story of the way in which man coaxes copper out of its ore and makes it ready to play the part that belongs to it in the work in the world.

CHAPTER VI

COPPER'S INSIDE STORY

Metals, like unfamiliar animals, and people of another race, look very much alike until they are known intimately. It is only after the acquaintance has ripened into recognition of their good and bad properties that the peculiar qualities of each metal can be utilized to the greatest extent.

Copper's inside personal story is being revealed by metallurgist, engineer, and chemist; their science and skill have penetrated into many of the complexes of copper; but the innermost depths of the red metal have not been probed any more successfully than the precise workings of the human mind. Enough is known, however, to explain much of the metallurgy by rote that arose through copper's long service to man. The examinations to which copper is subjected can show whether a particular piece is fit to undertake a given task and what treatment can be given it to put it in shape for a specified use. Metals are examined much more closely than ordinary, law-abiding citizens. They are photographed, given a certain treatment, and photographed again to see what happened. They are pulled apart, mashed, pounded, shocked with current, X-rayed, heated, and frozen. Their intimate composition, genealogy, and impurities are investigated. In fact, they are handled much more rigor-

ously than many people who have not kept within the law, and more is known about metals than about most criminals.

First, let us assemble the fundamental data on copper and compare them briefly with that of other metals. With copper's record before us we shall be able to discuss some of the explanations for its behavior that have been offered by metallurgical detectives. The record sheets will come from three laboratories: the physical laboratory where mechanical tests are made, the chemical laboratory where the chemist takes the never-pure metal apart element by element to discover its composition, and the photomicrographic laboratory where the interior structure of the metal is treated and photographed.

The mechanical engineers and metallographers in the physical laboratory look copper over, note its general appearance, its reflexes, and take its Bertillon measurements, as it were. It is comparatively simple to determine copper's inherent qualities, such as its color, weight, melting-point, expansion, and conductivity, because they are not affected markedly by the way in which the copper is treated. But strength, hardness, ductility, and fatigue are harder to put down on paper because not only do they vary widely with the treatment of the metal, but they are hard to measure. Copper's physical record reads somewhat like this: Name—Copper, often abbreviated to Cu. Color—Peculiar red, which is pinkish or yellowish on the fresh fracture of the pure metal, slightly purplish if it has much cuprous oxide. Weight—For electrolytic copper, rolled, 558 pounds per cubic

foot, or 8.89 times the weight of water. This varies somewhat according to the purity and condition of the copper; cast copper, somewhat porous, may be as low as 8.2. Melting-point—1083 degrees Centigrade equivalent to 1981 degrees Fahrenheit. Electrical conductivity—Copper is usually taken as the standard for conductivity comparisons, and called 100. The international standard value for the electrical resistivity of annealed copper is 0.17241 ohm for a column of copper a meter long and a square millimeter in cross-section. Linear expansion—For each degree increase in its temperature, Centigrade, copper will expand 0.00001678 of its own length. Thermal conductivity—0.918 small calorie of heat will be transmitted through one square centimeter of a plate of copper one centimeter thick in one second when the difference in temperature between the two sides is one degree Centigrade. Such is a portion of the record of copper under ordinary conditions. Some parts of it even in the reduced form in which it is presented probably seem unnecessarily complex, but such information in great detail is valued by those who study copper and predict what it can do. The other and more variable physical properties are somewhat as follows: Tensile strength—Varies with the condition and purity of the copper from about 22,000 to 67,000 pounds to the square inch. Typical values for various kinds of copper are: Cast, 25,000; soft and annealed at 200 degrees C., 38,000; hard drawn thin wire or hard rolled thin plate, 67,000. Compressive strength—Copper of good quality does not fail in the compression test by

fracture; it merely yields indefinitely and becomes flattened out. Hardness—This property is expressed in many ways. On the Mohs mineral scale of hardness, copper has a hardness of 2.5 to 3, between that of the crystallized minerals gypsum and calcite. The two methods of testing hardness in the physical laboratory are by the scleroscope, on which annealed copper varies from 6 to 7, and hard copper varies from 22 to 24, and the Brinell ball test, by which the hardness of annealed or cast copper is about 35 and hard copper may register as high as 100. Elongation—When the test specimen of copper is stressed so as to pull apart, this tension causes an elongation of the metal before fracture occurs and, depending upon the kind of copper, this lengthening will be from 40 to 50 per cent. for annealed copper to only 1 or 2 per cent. for hard wire. In strength and hardness it is difficult to compare different kinds of copper. The form in which they are tested, the kind of testing machine that is used, the treatment accorded the metal during test, and many other factors enter in to distort the result. As a consequence, national societies, particularly the American Society for Testing Materials, and the Government have prepared specifications for copper for various uses, which provide how the metal shall be sampled and tested, mechanically and physically.

Although comparison of other metals with copper is even more vague and inadvisable than the contrasting of different kinds of copper, a greatly condensed list of physical properties of the common metals, including copper, is given. It will probably allow you

to form an opinion as to the rank of copper in the world of metals. Do not be afraid to read it just because it is a table of figures.

Metal	Chemical Symbol	Atomic Weight	Density	Weight lbs. per cu. ft.	Melting point Degrees Centigrade	Electrical Conductivity (Copper 100)	Heat Conductivity
Copper	Cu	63.57	8.89	558	1083	100	91.8
Aluminum	Al	27.1	2.57	160.5	658.7	60.5	48.0
Gold	Au	197.2	19.3	1203	1063.0	71.8	70.5
Iron	Fe	55.84	7.8	487	1530	17.4	16.1
Lead	Pb	207.20	11.38	710	327	7.8	8.3
Magnesium	Mg	24.32	1.7	106	651	35.8	37.6
Nickel	Ni	58.68	8.3	518	1452	22.0	14.2
Platinum	Pt	195.2	21.5	1342	1755	17.2	16.6
Silver	Ag	107.88	10.5	655	960.5	106.2	100.6
Tin	Sn	118.7	7.3	456	232	12.0	15.5
Zinc	Zn	65.37	7.0	437	419.4	27.2	26.5

Chemical symbols are simply the nicknames or initials with which the scientist has dubbed the elements. They also stand for one atom of the element and all its properties. Atomic weight tells how many times heavier than hydrogen gas an element is when it is in its gaseous state. The figure for density tells the number of times the metal is heavier than water. As copper is surpassed only by silver as an electrical conductor, electrical conductivity is often expressed as a comparison with that of copper. The figure under "Heat Conductivity" allows a comparison of the amount of heat that metals will allow to pass through them. Note the close relation to electrical conductivity. The figure is the number of hundredths of small calories of heat transmitted per second through a plate one centimeter thick, per square centimeter of its surface when the difference of temperature between the two sides of the plate is one degree Centigrade.

The tensile strength of the pure metals is not so important as that of some of their combinations with other metals or impurities. By glancing over the figures below expressed in pounds per square inch tensile strength and comparing them with the figures for copper previously given, an idea of copper's place in metallic strength will be obtained. Brass, cast, 29,000 to 46,000, hard rolled, 55,000 to 75,000; bronze, 7000 to 48,000; iron, pure, 55,000, cast, 35,000 to 57,000, wrought, 48,000 to 53,000; carbon steel, 46,000 to 175,000; alloy steels, 75,000 to 330,000; aluminum, cast, 12,000 to 14,000, hard wire, 40,000; gold, 25,000 to 37,000; lead, 1780 to 3300; magnesium, 30,000 to 33,000; nickel, 38,000 to 150,000; platinum, 35,000 to 53,000; silver, 40,000 to 51,200; tin 4000 to 10,000; zinc, 4000 to 36,000. Tungsten wire has been produced with a strength of 450,000 pounds to the square inch.

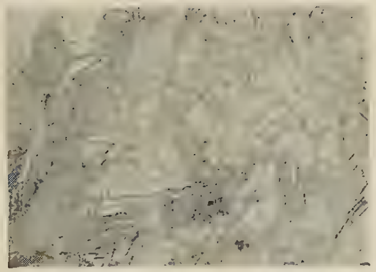
A method of analysis that has netted important results in better and cheaper metal and manufacturing practice involves polishing, etching, and then photographing the copper specimen through the microscope. Chemical analysis, despite the inroads made by the younger optical method, is extremely useful and necessary in examining copper from the time that it is mined until it is used. At virtually every stage of copper's journey to work, exactly how much copper there is in the material must be known. The chemist gives this information. Many reagents are used; to the chemicals themselves are added electricity and fire, and the chemist must be able to identify and accurately determine the quantity of all the impurities

that copper may acquire, intentionally or unintentionally. Fire assaying of copper containing ore, and the determination of lead, silver, gold, and platinum as well, is practised, and refined copper is often assayed electrolytically. Comparatively recently it has been realized that the gaseous as well as the solid constituents of copper must be found and listed in an analysis. Hydrogen and sulphur dioxide dissolve in copper and will be reported in analyses of the future. Nonchemical methods are being perfected to replace tedious titrations and filtrations, or, what is more often the case, to determine quantities of impurities in copper too small for the ordinary methods of the chemist to detect. When a flaming arc of copper is viewed with the spectroscope, it is found that each element has its own exclusive bands of lines that appear only when that element is there. The spectral lines also vary in brightness with the quantity of their metal that is present, and this difference in brightness is especially easy to determine when quantities less than a very small percentage are present, the area where quantitative chemical methods are often weakest. A few hundredths of a gram of material will usually suffice for spectographic analysis and with the spectograph impurities will be recognized that would require many hours of chemical work to detect. The faint presence of harmful antimony in lake coppers is quickly proved by the spectrum, and whether low conductivity in copper is due to arsenic, nickel, or something else may be quickly found out. Slight traces of such deoxidizers as boron, magnesium, manganese, silicon, and vanadium may be identified when chemical

analysis will fail to detect them even though days of effort are spent. As complex alloys of any kind are dissociated by heat into a spectrum that contains the tell-tale lines of each metal present, the secrets of the inventors of alloys and hardened metals are no longer hard to unravel. The spectrographic method is speedy and self-recording. In fact, the spectrum can be photographed by an assistant in the laboratory, deciphered by an expert at his leisure, and filed away for permanent record or future use.

The microscopist is the scientist who actually looks into the metal and sees how it is put together. The physical tester judges the metal by its qualities in a large piece, the chemist disintegrates the metal to investigate, but the user of micrometallurgical methods polishes and etches a specimen and then uses his microscope and his eyes or his camera. For the micrometallographic sleuth no trail is too cold, provided his metallic clue or sample has been untampered with and is unchanged. From an inspection of the sample he can often tell the past history of the metal's treatment and the reason for its excellent or poor qualities. Before an enlarged view of the metal is taken, a piece of the metal is looked at to determine whether the unglassed eye can detect any features. The eye is aided by employing an etching solution, such as ammonium persulphate, to reveal the macrostructure; although usually the relative size and arrangement of crystals, the features most often shown by unmagnified observation, do not need to be etched. The first step toward an examination under the microscope is the selection and grinding of the specimen. During the

cutting and polishing, it is usually important that the edges be left in their original condition, and copper is used to protect them. A layer of copper is electrolytically deposited on the specimen. If the specimen is of copper itself, a very thin film of nickel is deposited first so as to divide the original copper from the protecting layer. A rough grinding is followed by grinding with a finer abrasive; polishing that concludes with the use of impalpable alumina, grit-free, applied with very fine cloth, leaves the surface very smooth and ready for examination. Though some metals are examined unetched, usually a solution must be applied that will slightly dissolve some component of the metal and leave the remainder standing in high relief. For copper and copper-rich alloys, various etching reagents are used. Oxidation, the same process that takes place at some other places in copper's career, is of fundamental importance in successful etching of copper-containing metal. Many reagents that ordinarily have only a very slight solvent action upon copper and copper alloys may be successfully used for etching if oxidizers are added or oxygen gas is passed through the etching reagent while the specimen is immersed. With an ammoniacal or an acid solution the following oxidizers can be used as etching solutions: hydrogen peroxide, ammonium persulphate, potassium permanganate, potassium dichromate, chromic acid, ferric chloride. An etching reagent consisting of an ammoniacal solution of copper-ammonium chloride is electrolytic in its nature, and nitric and chromic acids, oxidizing in their nature, can be used. If oxidizers are used with concentrated ammonium



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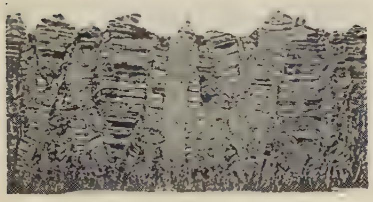

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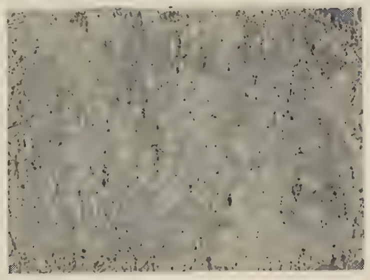

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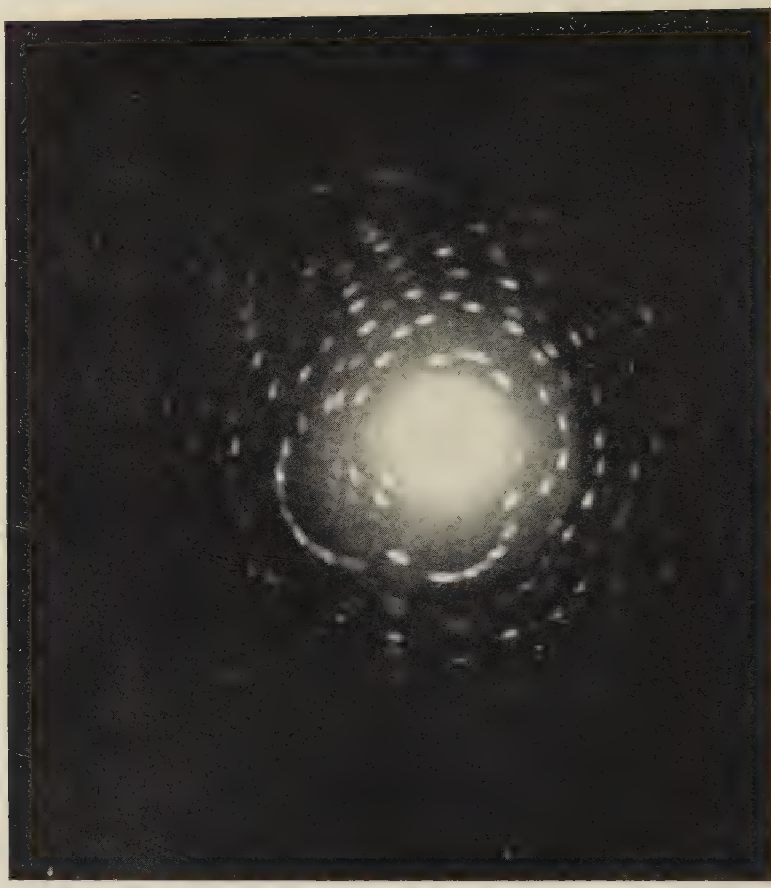
Courtesy of National Bureau of Standards

PHOTOMICROGRAPHS OF COPPER'S DIFFERENT APPEARANCES

The crystal structure of cathode copper just after electrolysis is shown in "a." The etched cross section of copper deposited on an electrotype, "b," shows off the tall crystals to better advantage. "C" is cast copper, and the dark intrusions are cuprous oxide. The elongated crystals in "d" show that this is a specimen of hard drawn cold copper wire, and "e" is the appearance of soft wire whose crystals have been relieved of the strain of drawing; "f" shows what the structure of a quarter inch hot rolled copper plate looks like. Magnification of "a," "b," "c" and "f" is 100 times, of "d" and "e," 250 times.



Photograph by Dr. R. W. G. Wyckoff, Geophysical Laboratory, Carnegie Institution of Washington

ATOM PLANES OF COPPER SULPHATE

The actual atoms of the crystal of copper sulphate are responsible for the symmetrical pattern of the crystal lattice shown in this photograph, for the wavelengths of the X-rays which took the picture are small enough to be reflected by those infinitesimal particles. Laue, a German scientist, in 1912 first proved, by means of a copper sulphate crystal, that X-rays could be used to photograph the crystal atom planes. A year or so later, W. L. and W. H. Bragg, in England, measured the distance between the atoms by making such photographs as this from different viewpoints, and then used a measured crystal to determine the wavelengths of X-rays. The magnitudes with which such measurements deal are in the neighborhood of a billionth of an inch, or about one thousandth of the wavelength of light.

hydroxide, it will give satisfactory results in etching. "Heat tinting," which consists of oxidizing unequally the different components, is valuable for certain bronzes.

Under the microscope, pieces of copper look so unlike that it is hard to realize that they consist of the same element. Slight impurities or differences of treatment remake the whole metallic landscape. The purest copper produced commercially, that which has been electro-deposited and not remelted, or has been remelted in a vacuum, consists of an aggregate of copper grains or crystals. When these crystals are present in the coating of copper on an electrotype, they show their twinning and their column structure to much better advantage. What a great difference five hundredths of 1 per cent. of copper oxide makes in copper's structure! In a piece of cast copper, the fallen forests of crystals have turned to a plane of copper with circular markings of copper oxide. This is the small amount of oxide that is left in the metal after it has been poled during fire refining. The cuprous oxide does not dissolve in the solid copper, and under the microscope its bluish-gray color with a red glow at the center of every particle differentiates it from any other inclusion in copper. It is even possible to use an area-measuring device on a photomicrograph and determine the amount of oxide present. The structure of cast copper is broken up by the heating, rolling, and drawing that it undergoes in the mill, the oxide is distributed through the copper in smaller pieces, and the structure takes on the appearance of the photographs showing hard drawn wire, soft wire,

and hot rolled sheet. When copper is drawn into wire and made hard by the process, the oxide forms itself into rows of fine globules, parallel to the direction in which the metal is worked, and the grains elongate in the same direction. When the wire is softened by annealing, the copper crystals seem relieved to be free from their strain and arrange themselves in an easier position. The grains of copper are very small; their diameters are from 0.0005 to 0.015 inch. Bismuth and lead, which show themselves as small particles, are other impurities that can be detected by micrographic methods, but other foreign material cannot be found by this method. The search for silver, gold, nickel, manganese, arsenic, antimony, zinc, phosphorous, and other impurities is left to the chemist.

The reasons for copper's pleasant properties and the formation of its microscopic landscapes of crystals, like the causes of the structure of the other metals, are major questions that scientists are attempting to answer to-day. Probably the most curious phenomenon of all nature is the way almost all the atoms in the world insist upon arranging themselves in orderly positions. Whenever they find themselves free to move, as when they make up a gas or are in a liquid, either a solution or a molten substance, the atoms rush about with a good deal of energy, but as soon as they, from cooling or other cause, find their range of activity decreasing, they face about and get in line with other atoms, the lines form squads, the squads platoons, and soon a crystal is built up. It is possible, by controlling conditions very carefully, to

build up the whole number of atoms into one very large crystal, but ordinarily there is too much hurry and confusion for this to happen. Crystallization starts usually in many places throughout the liquid at the same time. The near-by atoms hasten to join with those whose ranks are closing up, and the crystals grow. But before they have grown very large they begin to interfere with each other. They actually push against each other, and many different things may happen. One striking result of the struggle is twinning, when two crystals headed in opposite directions grow through each other. Often the crystals are squeezed into other forms than the one they are trying to assume, and queer, misshapen forms occur. This is especially likely to happen when from a mixture of two substances one begins to crystallize a little before the other. The crystals already formed resist the growth of the new crystals to such an extent that the second kind often have to slip in between, forming long chains of tiny crystals called "dendrites" because they grow in much the same way as moss between rocks. In a homogeneous material, the large crystals usually stop growing when they begin to interfere with each other, and the remaining atoms get together and build up smaller crystals in the chinks between them. There is no reason to suppose that this process should stop with crystals which we can see. In fact, smaller and smaller crystals have been found as more and more delicate means of detecting them have been invented until it is all but certain that the shape of the individual atom is a tiny replica of that of the perfect crystal.

Offhand, we should expect either that all crystals would have the same shape or that each would have its own characteristic shape. Broadly speaking, neither is true, although the trained crystallometrist can detect minute differences between crystals of one kind of matter and those of another. There are really just six types of crystals. Why there are so many—or so few—we do not know. Copper, like most metals, tends to arrange itself in cubes, or in double pyramids. As crystals are described, these forms are the same; each figure has three equal axes of symmetry at right angles to each other, running through the figure and connecting the opposite faces, or points, as the case may be. Another sort of crystal has only two of its axes at right angles to each other, while the third leans away from the vertical. This is called the monoclinic, "one inclined," and is the system of several of copper's salts, especially the carbonates. Again, all three of the axes may make angles which are not right angles, and the crystal that results from this arrangement is called the triclinic. The best known example of a triclininc crystal is copper sulphate, blue vitriol, which forms such large, beautiful, glassy shapes. Not all crystals, however, stop at three axes. It is not necessary to have a four-dimensional figure to have four axes, for three of the lines are at right angles to the vertical axis and make with each other angles of thirty and sixty degrees. The resulting crystals are hexagonal in shape. Copper does not use this system for its compounds. The remaining two systems are somewhat like the first one, and it is a rather technical job to recognize them. Metals usually cool so fast that

they have no time to do a good job at crystallizing, and perfect crystals in their structure are very rare. They form rather a mere frame or skeleton of their characteristic type.

The peculiar thing about the crystalline shape is that it seems that it cannot be destroyed. You may break a crystal, or even pound it to powder, but every breakage is along a cleavage plane so that the crystal only splits up into smaller crystals of the same type. It is readily seen that large single crystals have little strength to withstand rough treatment without injury. But a large number of small crystals growing together in such a way that their cleavage planes lie in every direction ought to give a much stronger mass. They do, and this is just what the metal-worker aims for. Since he cannot, to save his life, keep crystals from forming, he tries to keep those that do form reasonably small and well mixed up, or, as he says, he wants a fine-grained metal. The actual size of crystals formed in the different metals varies a great deal with the use to which the metal is to be put. No doubt you have noticed the mottled appearance of the surface of galvanized iron. This is caused by very large zinc crystals. And as there is no need for that zinc coating to exhibit tensile strength, hardness, ductility, or the other physical properties for which fineness of grain is necessary, it is perfectly practical to let the zinc crystals grow big. On the other hand, copper which is to be drawn out several thousand times its length into wires must be fine grained so that it will draw smoothly.

Metallurgists are vitally concerned in the funda-

mental connection between crystalline form and the hardness of the metal. They know that working a metal makes it harder and that it also deforms the crystals, drawing them out in the direction of working and squeezing and flattening them in the other direction. But the resistance of the crystals to this treatment and their tendency to return to their normal shape make the worked metal brittle as well. Therefore most metals, after working, must be heated to some temperature below their melting-points and held there for a while until the crystals have recovered from their strenuous experience. This is annealing. It restores the metal's malleability or ductility, but, unfortunately, softens it up again. A nice balance must be worked out between the two extremes. Sir George T. Beilby, an English physicist, formulated a theory which accounts for the hardening of metals under deformation. According to his hypothesis, the working of the metal, which makes the crystals slide over each other along slip-planes, acts like a polishing process and causes very fine particles to rub off the crystals and collect around them. These particles then flow together to form a sort of film around the crystals. Since the fine, amorphous material would have no crystalline slip-planes, it would be harder, for it would offer more resistance to deformation. There are some metallurgists who object to this theory on the ground that the finest particles in the thinnest copper leaf can be proved to be crystalline, and it does not seem probable that the working of large sheets of the metal could produce a greater proportion of amorphous material than the drastic ham-

mering which produced the leaf. Moreover, long ago it was found that electroplated copper three to five millionths of a millimeter thick has the properties of massive copper, and it is doubted whether cold work could produce fragments of this size. Again, others complain that if enough amorphous metal were produced to account for the hardening, all the crystals would be used up in a bar of copper by the time it had been drawn to five hundred times its length, while it can in reality be drawn out without annealing to five thousand times its length and still be crystalline But, when Beilby's hypothesis is modified somewhat by American metallurgists so as to be in accordance with the experimental facts, no better theory has been put forth to explain strain hardening. There is, however, still a great chance and much need for brilliant fundamental scientific work on the structure of metals.

Walter Rosenhain, the English metallurgist, has suggested, also, that a film or thin layer of amorphous metal exists around each crystal of metal, even when it is totally unstrained and in its natural state. This "inter-crystalline amorphous cement" theory has good experimental backing in the fact that when a piece of metal is pulled apart the breaks will occur through the crystals themselves and not at the boundaries between crystals. While some of this is theory, it rests on a firm foundation of facts about the very interior of metals.

With his recently developed sixth sense man has been able to probe into the very depths of metals and learn their structure. The X-rays, shorter and more powerful than the light-rays that we see, have made

known the arrangement of atoms in the metallic crystals with the same clarity with which they show the framework of the human body. When Laue found in 1912 that X-rays of uniform frequency or wave-length projected into a mass of fine crystals would be reflected in an orderly manner by regularly spaced atoms of crystals, he gave the metallurgist a new tool and he opened what had been a closed door into the interior of metals. W. L. and W. H. Bragg developed the X-ray spectrometer based on Laue's work, and the possibilities of this instrument in metallurgical work are scarcely realized even now. It has revolutionized our ideas on the constitution of solids.

The highest power microscope is feeble compared with the X-ray spectrometer. If two lines are separated by one thousand times the distance between two neighbor atoms in solid copper, these two lines would appear as one through the best microscope that the world knows. The microscope cannot hope to do any better, because it is limited by the wave-length of light. But with the X-ray wave-lengths of only one fourth the distance between two atom rows, man may peer into the crystals of metals, not with his eyes, but by using the sensitive photographic plate. The X-rays reflected will impress on the negative a series of lines or bands whose spacing will depend upon the geometry of the internal structure of the crystal and tell just how the atoms are arranged. Thus, with this most modern sense, we are able to "see" into metal and actually think in terms of the positions of the atoms in crystals.

The X-ray shows that atoms of copper form in the

same shape as the copper crystals that are seen under the microscope. The copper crystal is a cube with an atom at each corner and an atom centered in the surface of each face. Each side of this cube is just 3.60 Ångstrom units long, which in every-day extraordinary language is fourteen ten-millionths of an inch.

Having located the metallic atom, the metallurgist can find out more about it and its effects on visible metal, and he is proceeding to do so. At present it is said that only two X-ray spectrometers, one in England and one in America, are being used for metallographic research. These will undoubtedly multiply many times.

Very closely linked with the hardness of copper is its most important property, its ductility. Ductility is very difficult to measure satisfactorily, so that it is impossible to give figures comparing copper with other metals in this important respect. But it is copper's ductility that allows it to be drawn out into the fine wires that have made possible the enormous development of electricity. The ability to be rolled out into thin sheets is also included under the term, and the word "working" is used in practice to cover both rolling and drawing. When copper is worked its tensile strength and hardness are increased. Those who hold to the amorphous metal theory explain this change in properties as due to the formation of amorphous material, and indeed the grain of worked copper is finer than before the deformations took place. This working and change of grain size leaves the metal with a tendency for the crystals to resume their normal size and shape, and this is what is called a strain in the

structure. It makes the metal brittle and, under some conditions, may crack it. Hard-drawn trolley-wires usually get no further treatment after being drawn to their required gage, but most copper products are annealed after receiving their final shape to get rid of these strains in them. Heated to a temperature which will allow recrystallization without deforming the piece, the original alinement of the atoms is, at least to some extent, restored, the crystals grow, and the imposed hardness disappears.

The hardness of copper wire when it is drawn has some effect on the electrical conductivity, for it is found to be a poorer conductor than soft annealed wire by nearly 3 per cent. This is not a great deal, and the impurities which occur with copper and are not removed by refining affect the conductivity to a much greater extent. Especially prominent among these is the cuprous oxide which contact with the air always forms to some degree in copper that has been melted. This compound of oxygen and copper impairs both the conductivity and the ductility of copper; nevertheless it does not pay to reduce the copper until less than 5 per cent. cuprous oxide exists in it, for the other metals, such as lead, arsenic, iron, nickel, and aluminum, which make up the rest of the impurities in commercial copper would also be reduced from their oxides to the metallic form, and they are much less harmful when they remain as oxides. The conductivity of copper is decreased 3 per cent. when 0.01 per cent. metallic arsenic is present, 24 per cent. when 0.1 per cent. is present, and 38 per cent. when 0.2 per cent. is present. The matter is compromised by getting the

greatest possible proportion of pure copper without bringing in any extra disadvantages. Although these other metals are harmful so far as conductivity is concerned, they may prove quite beneficial for copper used other than electrically. Arsenic, for instance, helps copper carry on when it finds itself obliged to work in very hot places where there are harmful gases, as in stays for the fire-box of a locomotive.

The cuprous oxide that is always present in ordinary copper makes no trouble as a general rule, but it must be watched for two reasons. If copper is annealed at too high a temperature, too much oxide forms, and the copper is, literally, "burnt." This not only makes it brittle, but forms a starting-place for corrosion to eat in between the crystals where the particles of oxide lodge. Not only "burning," but "gassing" is an accident whose results to copper are likely to be fatal. The "gas" is steam formed within the grain of the metal, and this is the way it happens. Heating may take place in either an oxidizing or a reducing manner. If copper is heated in such a way that plenty of air can reach the hot surface, it will combine with the oxygen in the air to form its oxide. But if the amount of air is limited or if the air which is present cannot get to the copper because a flame is played closely over the surface, oxygen already in the copper as oxide feeds the flame and the oxide is reduced to metallic copper. Strangely enough, one of the products of flame is water, and so under these circumstances steam is formed. This would not make much difference if the metal being heated were liquid, for the steam could bubble up through it and escape, but to get out

from the solid copper it has to use its explosive violence which, of course, cracks the metal. This failure is sometimes produced during brazing of copper or its alloys, if the metal is not manipulated properly while heating.

The most frequent "discovery" made in copper metallurgy is that of the "lost art" of hardening copper. Often thrilling accounts of a new process that will revolutionize the copper business find their way into the press; periodically patents are applied for in the belief that the "mysterious" method of "tempering" copper supposedly evolved by the ancients has been refound. Of course there is nothing new or mysterious in hardened copper. Immense quantities are in use and more is being added daily. There are two well-known methods of hardening copper. As in the case of hard drawn copper trolley-wires and cold drawn copper tubing, rolling and drawing can produce a harder metal because of crystal rearrangement. Hammering has the same effect. The other common hardening method is that of alloying. Directions that are given in the ambitious but unscientific patents remind one of the metal-working formulæ of the alchemists of the middle ages. For instance: "Heat the copper to 260 degrees to 315 degrees and subject it while hot to fumes of burnt sugar and animal fat at a temperature below that necessary to form carbon monoxide."

Many times those who try to regain the lost art of hardening copper unconsciously use the common method of alloying: The metal is remelted and the process so manipulated that the copper becomes satu-

rated with cuprous oxide; the product is much harder and more brittle than pure copper. Cuprous oxide alloys with copper in exactly the same sense that metals do, and hence this process is only a variation of "hardening" by alloying. The fact is that there never was known to ancient men any art of mysterious copper hardening to be lost. The late Professor William Gowland of the Royal School of Mines, an authority on copper in antiquity, destroys this prevalent myth in the following words:

"The castings of knives, swords, etc., generally were hammered at their cutting edges, and it is to this hammering, and to it only, that the increased hardness of the cutting edges of both copper and bronze weapons is due, and not to any method of tempering. Much has been written about the so-called art of tempering bronze, supposed to have been practised by the men of the Bronze Age in the manufacture of their weapons; the hardness is also said to be greater than can be given to bronze of the present day. I should like to correct this error, as it can only have arisen owing to its authors never having made any comparative practical tests of the hardness of bronze. Had they done so, they would have found that the ordinary bronze of to-day can be made as hard as any, in fact harder than most, of prehistoric times, by simple hammering alone."

Copper has nine big assets in life. They are: its electrical conductivity, its capacity for conducting heat, its extreme ductility, its malleability, its high tenacity, its ability to alloy with other metals, its high scrap value, its artistic color and luster, and its

quality of withstanding corrosion. Its current-carrying capacity serves it principally when it is employed in the electrical field; its superior working qualities stand it in good stead when it is being prepared for the world. Its other qualities are not always important, but its hardiness in the face of the acquisitive elements is a point in its favor no matter where it is or how it is used. Red copper, uncombined, is naturally an unfriendly substance. In dry air the amount of the attack by oxygen is insignificant, and this is also true if moist air is free from much carbon dioxide, the gas that we manufacture and exhale from our lungs. If air is not present, dilute hydrochloric and sulphuric acids do not dissolve copper, though it is dissolved by nitric acid and by hot concentrated sulphuric acid. In the presence of air dilute acids attack it very slowly. But hot and cold water flow over copper year after year and leave it just as they found it.

If the conditions to which a substance is exposed do corrode it, the logical thing to do is to separate the material from its attacker. Iron rusts, forming an ugly red surface; therefore coats of paint are applied continually to keep the moist air away from uncorroded iron. The layer of iron oxide or rust that forms if paint is not used does not have the property of preventing further inroads of corroding material, but rather aids more air and water to get to the iron. On the contrary, copper, like the human skin that has been sunburnt, creates out of itself protection against the few natural combinations that tend to corrode it. And the coat of green carbonate, unlike iron oxide,

prevents the further disintegration of the metal and is more becoming to the average roof than a heavy coat of tan is to the average person. Copper patina costs much less than many coats of paint for iron or a trip to the sea-shore to acquire sunburn; the expense of copper's protection is included in the first and only price of a copper sheet, and there is no further charge as time goes on. Largely because of copper's superior ability to stick to its metallic state and the consequent lack of complaints as to its conduct, few extensive investigations have been made on its relative corrosion. In one case, however, copper was exposed to corrosion in competition with aluminum, iron, and steel with a victorious result. The observed rates of corrosion expressed as the decrease of thickness per year in fractions of an inch were:

	On Office Building Roof	In Railway Tunnel	In Smoke-stack
Copper (plain)	0.0000	0.004	0.014
Aluminum	.0011	.013	....
Iron	0.001–0.004	.15	.018
Steel		.12	.020

Copper thus protects itself well against aggression and in one case it has the ability of transferring a little of its immunity to another metal. When a little copper (about a quarter of 1 per cent.) is added to steels they are made more resistant to rusting when exposed to the atmosphere. This protection does not apply to the copper-bearing steels when they are immersed in liquids, and it is yet to be discovered just how copper prevents atmospheric corrosion.

A look into copper's personal history shows that it has many qualities to make it worthy of the reliance

and dependence that man places in red metal. Everlastingly on the job, it sticks to its freedom and under nearly all conditions has the ability of finishing the work assigned to it. It stands a large amount of hammering and much pulling; it only becomes harder when "treated rough." Coupled with its ease of working is a tenacity of purpose that is seldom surpassed among the metals. If it becomes embrittled through punishment, a little heating and slow cooling will restore it to tranquillity and an annealed state. As a carrier of impulses and power of an electrifying nature without loss in transit it is surpassed by only one metal, silver, which is too high-priced to be of much practical service. And copper is a good mixer. Useful as it is alone, it shows even greater ability when aided to a small extent by some other metal. But that is a story all to itself.

CHAPTER VII

COPPER'S CHEMISTRY

From a chemical point of view, copper is one of the bricks of which the universe is built. There are some ninety-two kinds of these elements, if we include several which are known to exist but are still undiscovered, and some or all of them make up not our own earth alone but every star as well. In order to realize the interesting place which copper holds among these elements, we must take the universe apart and see how it is made.

Let us take our earth as a chemist's tiny sample of the universe and give it what he would call an ultimate analysis. Into an imaginary furnace we shall place the whole of it: houses and lands; trees, animals, and people; mines and factories; oceans and the atmosphere that surrounds our globe. The chemist's furnace has various devices hitched to one end of it which sort out and imprison the few elements of which he knows his sample is composed. To our gigantic furnace let us imagine some such attachment that will separate element after element as they come out. Our interest in observing nearly everything lies in its resemblance to other objects or its difference from them. As we watch the elements issue from the exit pipe of our furnace and line themselves up in order

we are struck with the great variety of appearances which our "bricks" present.

The most familiar in appearance are the metals, which make up more than two thirds of the whole exhibit. Some of them we recognize at once. Our familiar copper, iron, nickel, zinc, tin, aluminum, gold, silver, mercury, lead, and platinum are all here. There are many more that we have never seen before. All have the characteristic shiny "metallic" look. Most of them have the same color, or lack of color. Silver and platinum, zinc and lead, tin and nickel, all look very much alike. We are accustomed to think of that gray as the color of metals, with copper and gold as shining exceptions. Now we see other reddish and yellowish metals among the lot. Manganese and bismuth have the red tint, while neodymium, præsodymium, and cesium are yellow. Mercury is the only metal that occurs as a liquid.

The remaining third of the elements present every variety of appearance. Ten are gases. Of the division of non-metals also one, namely bromine, is a liquid.

As this company of between eighty and ninety individuals draws up before us, the questions almost inevitably arise: Why this great number and variety of substances? How did they all come to be?

If we now bring in a set of chemical reagents and put the elements through their paces, we may again compare them. Some of them are not affected in the least. Suppose we group these together and set them to one side. All are gases. We meet them every day, for they are a part of the air that we breathe, but

they are as invisible as they are chemically inert. The first and lightest of the group is helium, which is sometimes used in the gas-bags of dirigible air-ships. It is named for the sun, where it was first discovered. The next one is neon, whose name means "new," argon, the "lazy," follows; then krypton, the "hidden"; and xenon, the "stranger." The last known member is niton, a descendant of radium. Its characteristics differ somewhat from those of the other elements of this group as one would expect of a member of the erratic radio-active family. Although the above elements are so uninteresting in their chemical behavior, they play a considerable part in answering our questions as to how the elements come to be. We shall meet them later.

In experimenting with the remaining elements, which are the chemically active ones, we find the metals and the non-metals taking sides against each other. Let them but find themselves suitably disposed in their surroundings—say, dissolved in water—and free to move, and each atom hastens to don his electrical charge and deploy to a strategic position. The metals in general rally to the positive cause, the non-metals to the negative. But here, as in many another conflict, there is bound to be some disaffection in the ranks. Some companies go at it with great singleness of purpose, determined to neutralize every opposite charge in the neighborhood; others are of two, or three, or four minds about the matter, and are rather neutral in their behavior.

We cannot here go into the characteristics of all the elements, fascinating as they are in their almost in-

finite individualities. The point upon which we must fix our attention is their electrical behavior. We might skim over the valence, or combining power, or "elective affinity," of copper and the other elements by using such similes as may be drawn from a battle, as we hinted above, or from marrying and giving in marriage, but it is believed that something of the actual mechanism of chemical action will give a better conception of just what a compound is; and the actuality is so bizarre that similes pale in interest beside it.

Let us look more closely at our rows of elements. Any one of them will do as a sample, and so we shall choose copper as the most interesting to us at the moment. We shall suppose our sample in the state in which we like to see it—beautifully regular in form, smooth of surface, and brightly polished. Suppose we look at it through a microscope. The surface that a moment ago seemed perfectly smooth now has the profile of rugged mountains and precipitous valleys. Its evenness was due only to our coarse perceptions.

Taking for our aid a bit of magic,—whose lack causes scientists to go to all sorts of circuitous lengths to learn the things we shall now see,—let us take a fairy's embroidery-needle and pick off a tiny pebble from one of the copper mountains our lens has revealed. Now we change the objective lens of our instrument and magnify this speck in turn; what we see is a large number of shining balls, not packed together like shot in a box but flying about through space with a random motion. Over here two seem about to have a head-on collision! Closer together they rush; then do a half-turn about each other and rush away in

other directions. Here one coming straight toward the lens—for they travel in three-dimensional space —gives the opportunity to watch it a moment longer than the others. While it travels it is spinning, spinning, without incitement, without end. Look with the other eye over the frame of the instrument. The system that contains this eternal tireless motion is just an ordinary lump of hard, cold, inert metal.

Of course, you identify the flying spheres which you have just seen as atoms. Now no man has ever yet looked down the barrel of a microscope and seen an atom. The limit of our vision, even with the most powerful lenses, is reached long before so infinitesimal a thing can be brought into focus. Yet the student of these affairs knows far more about what atoms do and even what they look like than he does about many other things that go on in plain sight. From the time—only a little more than one hundred years ago—that John Dalton proposed the atomic theory, the conquest of the atom has proceeded at a rapid pace. The idea was, at first, that the atom is the ultimate particle, and beyond it nothing smaller can be. Let us catch one of our flying atoms, turn upon it the "fine adjustment" of our magic microscope, and see about this.

We are looking at *one* atom. Behold, its oneness has vanished. We look to see something strange and novel, and we find only what we may see any clear night—a starry sky! There are not so many stars in this firmament, however. In fact, we have just one large solar system. And, looking at it more closely, it is different from the only other solar system we know—the one in which we live. In our system each

planet has its individual orbit; in copper's *atomic* system, each orbit is shared by a number of planets which keep at regular distances from each other. There is another difference, too. Jupiter and Venus and Saturn and Mars and the earth and the asteroids and all the members of our solar family have their orbits in virtually one plane. One could look at our system edgewise and imagine all the planets running around on a disk, perhaps something like balls on a roulette wheel. Copper's system is more what we should expect to find in our three-dimensional universe, for the orbits of all its planets, taken together, outline a sphere, or, better, an ellipse.

The modern scientist, strangely enough, knows not only how these sub-atomic structures look but what they are made of; and, although they make up the material universe, *they are not matter*. This sounds like the adventures of that immortal pair, the *Walrus* and the *Carpenter*, does n't it? The lines might run something like this:

> We found each atom looking like a hard and shiny ball,
> And that was very odd because they are not things at all.

Well, to end the suspense, they are electricity. The planets or electrons in their orbits are, apparently, granular masses of negative electricity; and the atom's sun, or nucleus, at the center of the system, is composed of positive electricity, and also, from the evidence that has been gathered recently, of a corpuscular nature. We know that every one of the elements, pursued down to its sub-atomic structure, is made up

in exactly the same way. For the actual spacing of the electrons it is necessary to resort to hypothesis. If we consider the known facts about atom structure we find that the main items are as follows: All elements are made up of the same units, namely, grains of positive and negative electricity; each element has its own definite unit-weight, which is expressed as so many times the weight of an equal amount of hydrogen, the lightest of them. If the elements are arranged in the order of their atomic weights the properties by which we distinguish them vary by gradual change from those of one element to the next until the whole series from one kind of properties to a kind exactly opposite has been completed, and then the series swings back again. The latter statement is known as the Periodic Law, and is one of the most important generalizations that has ever been made in the field of science. The chemist phrases it, in his concise language: *The properties of the elements are periodic functions of the atomic mass.* In addition to the above demonstrable facts, we have excellent reasons for believing that we know the exact number of electrons in the atom of each element, or at least a submultiple of it; and we strongly suspect that the weight, or mass, of each element is so concentrated at the nucleus that the mass of the electrons is inconsiderable beside it.

The terms of the problem are now stated. We have a number of heavy blocks, all alike, and a number of light blocks, also identical. By placing one or more heavy blocks together, and arranging around this group in three dimensions, varying numbers of the

light blocks, we must construct about ninety figures which shall differ not only in the weight of the whole figure but in some other manner which will account for the differences in properties of the elements. The solution is obvious. The figures must differ in the arrangement of the blocks. Therefore the arrangement of the electrons about the nucleus must account for the chemical properties of the elements. From this, one would expect elements resembling each other to have a similar arrangement of electrons. How shall we find out just what these arrangements are? We might try an analogy. There is a classical experiment often performed in connection with the study of magnetism. A number of ordinary steel sewing-needles are magnetized, and each one is pushed through a cork. All are then floated in water with the same pole—for example, the positive—sticking up. The small magnets are then free to move in two dimensions, on the surface of the water; and, of course, the repulsion of the similar poles keeps them at an approximately equal distance from one another. They will accordingly form the geometrical figures most stable for the number of needles used. Four, naturally, will place themselves as the corners of a square. More can form circles, but soon there are too many to stay in the ring comfortably, and one takes its place at the center. Large numbers of the needles tend to form concentric rings, where each outer ring holds more needles than does the one inside it. These figures represent the most stable forms for the interaction of the forces present. It will readily be imagined that particles such as electrons, repellent to one another, yet held

near one another by some central attracting force, will assume similar space relations. The only difficulty in showing exactly how they look in three dimensions is the impossibility of allowing the models perfect freedom of motion. However, mathematical calculations of the probable arrangement can be made, which show that the principle of the grouping is much the same except that the rings of the above experiment become hollow concentric spheres or shells. This idea of spatial configuration has been elaborately worked out by G. N. Lewis and Irving Langmuir to account for the properties of the individual elements.

If we are to build up element after element by continually adding electrical particles to the preceding ones, it is obvious that the same *configuration* of electrons may serve for many elements, and that the atom of a relatively simple element may act as a sort of core for a more complex one. A little while ago we left the group of inert gases with the promise that we would return. Let us now consider them from the point of view of atom-pattern. The first of them, helium, is the second lightest atom known. We have reason to believe that its atom is made up of a nucleus and two electrons. The fact that the substance is inert is explained, according to the theory, as the result of perfect balance of the forces within the atom. The picture which at once presents itself is of one electron on each side of the nucleus. That is, no doubt, the real arrangement. The system is so extremely stable that *the helium form is the inner core of every heavier element.* It is not helium as such that is there. Every succeeding element has more positive particles

in its nucleus than has the lighter one before it. But, with the exception of hydrogen, which owns but one electron, every element has those two electrons holding each other in checkmate as its inner shell. We may imagine that, in the shake-up caused by some atomic catastrophe, two electrons might seize a sufficient number of positive particles from the nucleus and emerge as helium. Something like this, indeed, does occur in the case of radium and many other radioactive substances from which helium is given off as they disintegrate. The residue, having both the number of its particles and their arrangement changed, has thereby become transmuted into another element.

But if we are to have more than two elements we must add another electron to the helium arrangement. It is understood that more positive units are added to the nucleus as we proceed, but since they do not affect the structure they need not be mentioned. We may easily imagine a stable arrangement of three electrons in an atom, but that configuration appears not to exist in nature. Instead, the new electron betakes itself out beyond the first two and starts a new spherical orbit, or shell.

If balance of forces and relative immobility of electrons accounts for the properties of an inert chemical substance, the new element with a solitary electron in its outer shell should be chemically active, and so, in fact, it is—the metal lithium. But the next one, with another electron, would be less active, and this theory is also borne out by the metal beryllium. It might be just as inert as helium but for the fact that the second shell of the atom is larger than the first and

consequently can hold more electrons. As a matter of fact, it holds eight, and not until all eight are present will the character of helium reappear. When three electrons enter the second ring of the atom, we get the element boron, parent of our familiar borax and boric acid. Its activity, as we should expect, is less than that of beryllium, its predecessor. With the next, carbon, the shell is half full. A certain balance, although not complete, would be expected. And indeed, its properties form a turning-point for the elements of this series. The preceding ones are of the type known as positive. If they are free to move in an electrical field, they seek the negative pole, because unlike charges attract each other. The elements following carbon are negative and are acid-forming substances. Their chemical activity increases now until we reach fluorine, the seventh element beyond helium, which displays the climax of chemical activity for negative elements. Beyond fluorine comes neon, twin of helium. The second shell of the atom has been filled.

If we were constructing an imaginary figure from concentric spheres, we should certainly make the third shell larger than the second. But nature does it differently. The next sphere, beginning with neon and ending with chlorine, also contains eight elements, and each one of them repeats the fundamental properties of the element in the corresponding place in the preceding series.

The relationships between the elements were discovered about sixty years ago—long before an electron was even dreamed of. The Russian chemist Mendeléjeff formulated a table showing how the transition in

THE PERIODIC TABLE OF CHEMICAL ELEMENTS

Series	O	I	II	III	IV	V	VI	VII	VIII
1	Helium	Lithium	Beryllium	Boron	Carbon	Nitrogen	Oxygen	Fluorine	
2	Neon	Sodium	Magnesium	Aluminum	Silicon	Phosphorus	Sulphur	Chlorine	
3	Argon	Potassium	Calcium	Scandium	Titanium	Vanadium	Chromium	Manganese	Iron Cobalt Nickel
		Copper	Zinc	Gallium	Germanium	Arsenic	Selenium	Bromine	
4	Krypton	Rubidium	Strontium	Yttrium	Zirconium	Niobium	Molybdenum	*Unknown*	Ruthenium Rhodium Palladium
		Silver	Cadmium	Indium	Tin	Antimony	Tellurium	Iodine	

The table is not complete as here given. The places of many of the heavier elements in it have not yet been determined satisfactorily, and it is thought to be less confusing not to attempt to include them. It may be of interest, however, to state that gold occupies a place similar to copper and silver, mercury to zinc and cadmium, radium to calcium and strontium, and lead to tin and germanium, while platinum is one of an eighth group trio with osmium and iridium, with which it is is frequently alloyed both for jewelry and in scientific apparatus.

properties is related to the atomic weights. Part of this table is shown herewith. The "Periodic Table" is vastly useful, but its peculiarities are just beginning to be understood. The elements beginning with helium are written in a horizontal line which ends with fluorine. Then the inert neon is written at the beginning of a second line and placed just below the inert helium. The active, very positive sodium comes next, right under the still more active lithium, and so on until chlorine finds its rightful place under fluorine.

When he had got so far, we may well imagine that Mendeléjeff was sure he had the key to the universe. But the fascination of science lies in the fact that the solution of one problem only leaves us face to face with a greater one to tempt us on. The next problem in the relationship of the elements comes in the very next line. Series 3 of the table starts off just as usual with four quite predictable elements. The first four differ no more in their properties from the first four of series 1 and 2 than those series differ from each other. But following them comes a long list of elements which not only fills the table twice but flows over into an extra group, and this group holds not one element, like the others, but three. Nevertheless, the plan which series 1 and 2 follow has not been totally abandoned, for the last three elements of this "first long period" tally with the last three of the first two series. A second long period follows the first, and corresponds with it member for member. Chemists have always been rather irritated by these long periods, and particularly by those Group VIII trilogies. The explanation of that Gordian knot in the middle of a long string

of metals has been too much of a puzzle. Group VIII has been nicknamed the "hospital for the incurables."

Before taking up the problem of the Group VIII triplets, however, we must fix firmly in mind the fact that most of the elements never exist uncombined. Copper, silver, and gold, and the gases of the air are the only elements that at all commonly occur native. The existence of the other elements in elementary form is due to the work man has expended on their ores. As soon as he relaxes his vigilance, back they go into combination again. If we carry this thought down to our consideration of the atom, it must appear that two or more dissimilar atoms can together, in such cases, effect a more stable arrangement of electrons than can one atom alone. And if we remember that when a compound is dissolved in water its molecule splits up into the positive and the negative components, each carrying an electrical charge, the whole mechanism of compound forming is clear. The electrical charge comes from the one or more electrons that the atoms *shared* in the molecule. When the compound dissociated in the water these electrons went with the wrong half. The charge represents the desire of the one to give back the electron and of the other to get it.

If an elementary nucleus is so little attached to an electron that it will lend it to any other element that will take it, there must be a very unstable structure-pattern in its atom. The elements of Group I fulfil just these conditions. We have seen that they have each just one more electron than the very stable Group O element just before. If an atom of lithium can

"lose" one electron, the remaining ones form the pattern of the inert helium. And if it can lose this electron to a very negative element, like fluorine, which needs just one electron to assume a form as stable as neon, it is decidedly to the advantage of both elements to combine. Of course, they do not form a mixture of two inert gases. It is the form and not the substance that is changed. What these two very active elements do form is a nicely crystallized, colorless salt, with a very high melting point (801° Centigrade) and other evidences of great stability.

And now for the solution of the Group VIII mystery. These metals lie exactly in the middle of the long periods. Their electron patterns are quite as regular in form as those of the Group O elements. The fact that the shells do not contain their full quota of electrons prevents their being chemically inert, but their near neighbors in the Periodic Table tend to assume their form by gaining or losing electrons much after the manner of sodium and fluorine in reverting to the inert form. Neon and argon, each with eight electrons in the outer shell, have the cube as their atom-pattern, with an electron at each corner. Iron, with eight electrons in its outer shell, has the same arrangement. In this atom the diagonals of all three cubes coincide. Cobalt and nickel, the other members of the group, find but a simple modification of this structure necessary to take care of their one and two extra electrons. Cobalt places its over one face, making a sort of obelisk with square sides and a pointed top; nickel adds an electron over the opposite face

and forms a square-sided prism, pointed at both ends. Iron, cobalt, and nickel are very much alike in the kind of compounds they form.

Copper begins to break away from this influence. Its struggle to do this gives rise to some curious properties. It was placed long ago in Group I of the table, and there are many reasons for having it there, but on the other hand it differs in dozens of respects from the earlier inhabitants of this section. Heretofore the break between the right-hand and the following left-hand groups in the table has been sharp and sudden. In the long periods it is gradual, and copper may well be considered a transition element. Fluorine and sodium, with neon between, have almost nothing in common. We might fancifully describe neon as bearing the relation to fluorine and sodium respectively that the cocoon does to the worm and the butterfly. It is the transition between two quite unlike forms. But copper reminds one of the Hindu idea of a transmigratory creature which carries the mark of the old life on into the new.

And so we find copper leading a double chemical life. As "cuprous" it fits into the same category as sodium, losing one electron, or "acting with a valence of one." Many of its compounds are colorless, as are those of all alkali metals. On the other hand, as "cupric," its characteristics revert to the highly colored salts of the metals that precede it, and we find its principal salts displaying the green and blue colors with which we are most familiar. Colors of salts, caused as they are by vibrations of electrons within the atom, furnish a fascinating check for theories about the probable

stability of atom structures. So we see that, although the cupric salts are the more usual, the cuprous compounds, with their paler colors, fore-shadow the pattern by which the following elements will be built.

CHAPTER VIII

COPPER'S JUNIOR PARTNERS

No matter how extensive the qualifications of a person and regardless of his accomplishments along certain lines, there are many things that he can do better if he coöperates with other people. Copper, despite its high qualifications for conductivity and other performances when it is strictly alone, can achieve many of its ambitions better if it has the coöperation of some of the other metals. For this reason alloys, or metallic partnerships, are formed every day. Fortunately copper is a very good mixer in metallic affairs, and there is hardly a metal with which at some time or other it does not go into business to perform a certain task. In its ability to coöperate it is superior to most people.

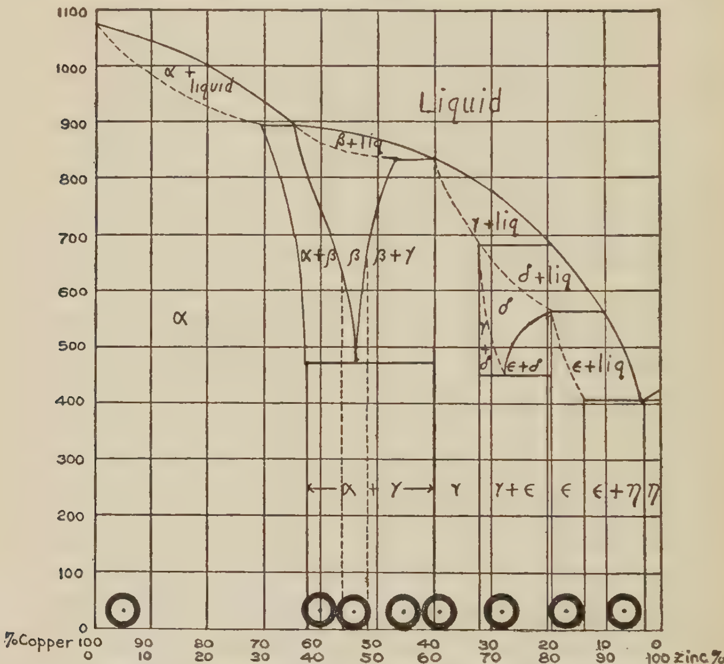
The most frequent junior partners of copper are zinc and tin. Copper and zinc trade under the general firm name of "brass," and copper and tin form "bronze." Each metal does not always contribute the same amount of capital to the partnership for each venture, but new combinations are often formed for each undertaking. Of course there are a series of standard partnership agreements that are used whenever possible, but when special occasions require it special agreements are often entered into. Aluminum and nickel are two other partners of copper that

prove very useful, and the utility of aluminum, which is rather new to metallic business, is increasing as alloys of it and copper are given experimental and practical trials. Other metals alloy with copper frequently, but usually more than one other metal joins in the partnership. Three and four metals, including copper, are common in alloys, and at times copper is one of six elements joining together. These agreements and the way in which they are entered into are somewhat complex. Let us first content ourselves with seeing how the two-element partnerships that include copper as senior partner conduct their business.

When two metals form a partnership, each one usually changes its habits somewhat and adapts its disposition so as to get along well with the other. The degree to which the resulting partnership acts as one or the other partner would act alone is, naturally, dependent upon the interest which each one takes in it. A combination of ninety-nine parts of copper and one part of zinc we should expect to be very much like copper, and one of ninety-nine parts of zinc to one of copper to be not very different from pure zinc. But when we observe something nearer a fifty-fifty agreement it is evident that each metal has tried to meet the other half-way.

In order to get a general idea of the various contracts into which two metals may enter, let us leave "this bourne of time and space" and enter the country of metals whose map is printed herewith, a land where a new set of dimensions is in force. This is the solidifying region of the copper-zinc series, the land of brass. In it every possible combination of those two

metals has its place. Farthest to the left dwells copper when it is alone. The home of zinc is on the right-hand margin. The headquarters of the various partnerships lie in the region between.



CIRCLES REPRESENT THE COMPOSITIONS OF SPECIMENS SHOWN IN PHOTOMICROGRAPHS.

MAP OF BRASS

The curve which cuts off the upper right corner marks the lower boundary of the region where these metals can exist as liquids. The melting-point of pure copper is the point where this curve crosses the left-hand margin line. This temperature at which copper

changes from liquid to solid is 1083 degrees Centigrade (about 1981 degrees Fahrenheit). Zinc melts at a temperature much nearer to those we are familiar with, 419 degrees C. (786 degrees F.).

The copper-zinc plane is a strange country to us, yet we can trace on the diagram the place where these substances touch our daily lives. You observe that the straight lines crossing the page represent hundreds of degrees of temperature. The bottom line of the figure is zero on the Centigrade scale, the freezing-point of water. The next line, marked 100 degrees, is the temperature at which water boils. Our ordinary lives are spent well within these limits. The large black circles represent the composition of the principal types of brasses. Only a few of these are of great commercial importance.

Now, in order to appreciate the meaning of the various fields marked off below the solidifying line in the diagram, let us make, in imagination, an investigation of the alloys which copper and zinc will form. We will take a number of crucibles and in each place a quantity of each of the metals. We are at liberty to mix the two in any proportion that we see fit, that is, we may *vary the components*. It will be interesting to try to cover the whole field, and so we may select 101 crucibles and vary the composition by steps of 1 per cent. The first crucible will hold pure copper, the second will blend 99 per cent. copper with 1 per cent. zinc, the third will contain 98 per cent. copper and 2 per cent. zinc, and so on, until the last one will have no copper and 100 per cent. zinc. Let us now heat all the crucibles until the metals have melted and

the mixtures have become thoroughly blended. We cannot heat them all in the same furnace, for the zinc would boil away to vapor before the copper melted, but we can imagine such details all nicely adjusted in a series of furnaces, so that we can allow the contents of one crucible after another to cool down while we watch the process and the indicator which shows the temperature at which the changes happen. The first crucible to show any change will be No. 1, containing copper alone. A trifle above 1080 degrees the bright, molten metal will begin to freeze over on the surface, especially around the edges. And now we notice a peculiar thing. The pyrometers which are measuring the heat of the other crucibles will show that their temperatures are gradually falling, but, so long as the copper is solidifying, the one connected with Crucible No. 1 will register a constant temperature. It is characteristic of chemical elements and compounds that they freeze and melt sharply at a single point. What substances that are not elements or compounds do is by this time being demonstrated by Crucible No. 2, in which 1 per cent. of the copper has been replaced by zinc. This material began to harden a little below copper's freezing-point, but its temperature did not remain quite constant. It had cooled off a few degrees before the last of the alloy became a solid. Crucibles 3 and 4 and 5 and so on have been behaving in the same way in the meantime, and in some cases the temperature has dropped more than fifty degrees while the melt was becoming solid. Those alloys containing up to 30 per cent. zinc have now been cooled below their freezing-points. Let us pause a moment

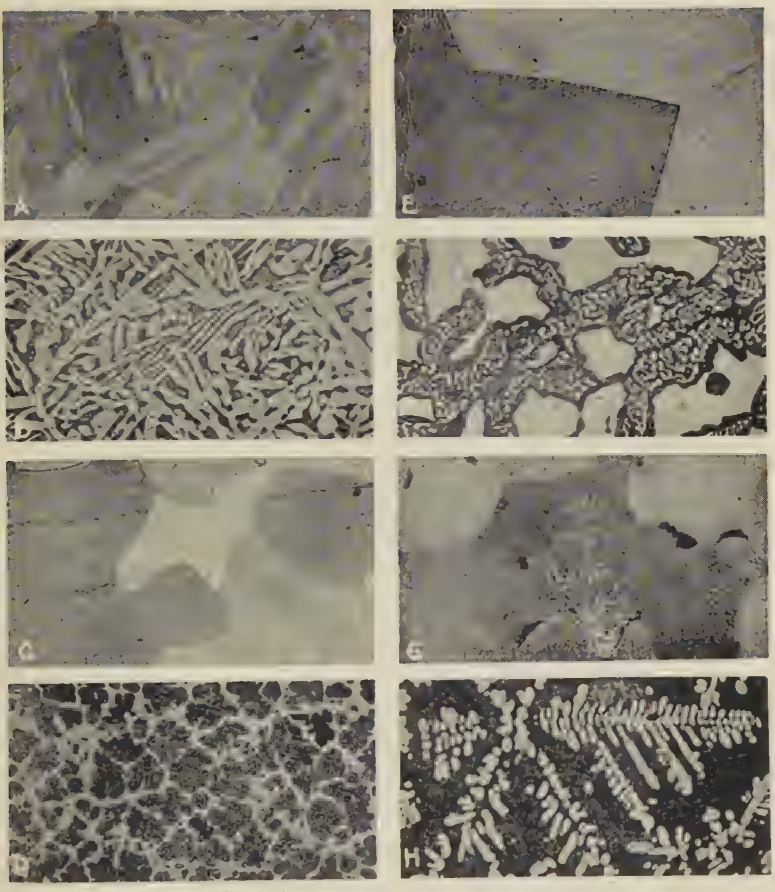
here and see just what we have found out. The temperatures at which the alloys have solidified have, so far, decreased as the percentage of zinc became greater. They have followed the upper, heavy curve in the diagram. That line, then, gives the freezing-points of the alloys. But, instead of a definite point at which they freeze all at once, we found that they may cover quite a range of temperature in that in-between state. The temperature at which they stop freezing and become entirely solid is, therefore, important, too. If we plot that temperature for each of the alloys, we find that we have drawn the lower curve, the dotted line in the diagram. If now we were to heat the alloys up again, we should find them beginning to melt at the lower point and becoming entirely liquid at the upper. The upper line, then, bounds this melting state on the liquid side, and the lower is its boundary on the side toward the solid region. The names of these lines, "liquidus" and "solidus," are obvious in meaning.

It is always interesting to find out what a substance that we have made looks like. As soon as our high-copper brasses have cooled down enough so that we can distinguish their color, we find a series of gold-colored metals, varying in shade from that of their parent copper toward the well-known brassy yellow. The alloys which contain 10 to 20 per cent. zinc look especially like gold, and are known under various names, such as tombac, Manheim gold, pinchbeck, French oreide. Such metal can be cast and stamped, and is used mostly for ornamental work. It is not unlikely that this material was made by the alchemists in their at-

tempts to refine copper to gold, and palmed off, either sincerely or fraudulently, on the poverty-stricken princes of Germany who were the alchemists' most hopeful backers.

To the metallographers, the alloys we have just mentioned are all the same substance, known to them as "component alpha." Although they are of different chemical composition, and have very different physical properties, they are identified by a common appearance when examined through a microscope. The study of the microscopic appearance of metals is one of the important newer sciences which has unlocked for man the door to the understanding of phenomena that go on just beyond his ken. After etching the metal to remove the surface skin, the pattern of crystal structure is studied under a medium-high magnification. Some alloys are found by this means to be homogeneous substances. Others consist of mixtures of two distinct types of metal. In such cases, one usually crystallizes out first, and appears as little islands in a matrix of the second alloy. Alpha is one of the homogeneous alloys, and a picture showing the nature of its crystal structure is shown in Photograph A.

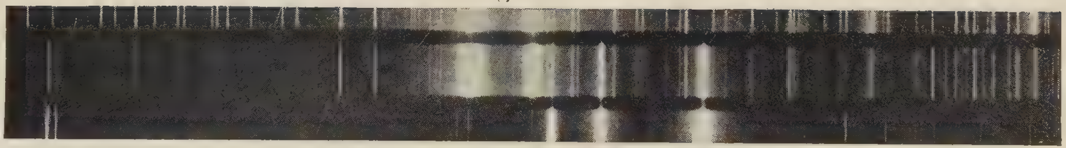
To return to the constitution diagram of the brasses, and our imaginary experiments, we find that when we examine those alloys which contain around 60 to 40 per cent. copper a different sort of metal has resulted from the fusions. The liquids in this series of crucibles have had to be cooled still more before they would solidify. The color of the cooled products is more yellow than the reddish or gold-colored alloys in the



Courtesy of National Bureau of Standards

STRUCTURE OF VARIOUS BRASSES (COPPER-ZINC ALLOYS) SEEN THROUGH MICROSCOPE, MAGNIFIED 100 TIMES

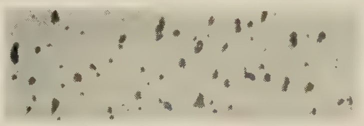
The proportion of copper and zinc in the photographs varies as shown on the constitutional map of brass, where the circles, left to right, designate the composition of brasses from "a" to "h." "A," "c," "e," and "g" are simple in their structure, while the other four alloys are duplex. "A" is composed of alpha brass and "c" is beta brass. "B" is a cross between "a" and "c," the dark portion is beta brass while the light is alpha. "E" is gamma brass and the dark splotches in "d" are gamma, the light background is beta as in "c." "F" is a mixture of the gamma of "e" and the darker epsilon brass of "g." The light, fern-like material in "h" is also epsilon brass, and the remaining black portion is zinc-rich eta, which is not pictured separately.



Photograph by Dr. W. F. Meggers, National Bureau of Standards

SPECTRAL PROOF THAT BRASS CONTAINS COPPER AND ZINC

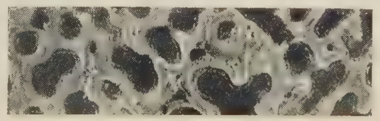
When an electric arc or spark is made to travel between pieces of a metal, the light obtained can be broken up by a prism and made to reveal the deepest secret of its composition. These are photographs of copper, brass and zinc. Each line has a place and meaning all its own. These spectral lines are caused by electrons within the atoms of the metals changing from one stable orbit to another under the influence of the heat of the electricity. The spectroscope, the instrument for breaking up the light and showing its lines, has been used to determine the material that composes the sun and the other astronomical bodies. Now it is being turned toward combinations of metals. Note how the spectrum of brass contains and exactly matches all the lines of both the copper and the zinc spectra above and below it. That is proof that brass contains copper and zinc. The lines in this photograph are all made by ultra-violet vibrations, and therefore are visible to the camera but not to the eye. The wave-lengths of light bands in spectrum work are stated in Angstrom units. An Angstrom unit is about one ten-billionth of a meter.

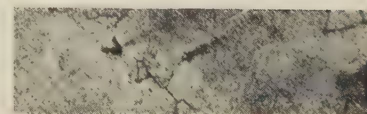


Courtesy of National Bureau of Standards

Cheese-Like Structure of Leaded Brass

Each black spot, or "hole," represtnts a globule of lead added to improve the machining qualities of the alloy. The specimen is unetched. Lead does not alloy with copper like other metals; it simply scatters itself throughout the copper or copper alloy in small pellets. Magnified 100 times.





Courtesy of National Bureau of Standards

How Prolonged Heating Will Change the Inside Appearance of an Alloy

An alloy consisting approximately of 88 per cent copper, 10 per cent tin, and 2 per cent zinc when cast has two alloy constituents which form the pronounced dendritic pattern of the photomicrograph on the left. Heating will cause one of these solids to dissolve the other. The view on the right shows the condition after heating for 8 hours at 600 degrees Centigrade. The alloy consists of a nearly homogeneous solid solution. Magnified 100 times.

former series. The properties of these brasses are quite different from those composed of the alpha component. While the brasses, made of alpha, can be drawn into tubes and wires when they are cold, this new series of brasses have very little ductility in the cold, and must be drawn or rolled at least partly at high temperatures. A glance at the diagram will explain this property. Alloys of the compositions mentioned cool to form a different component, or phase, from those with higher copper content. It is called "beta." But it is not an entirely stable form at lower temperatures. The field in which it is at home dwindles as the temperature falls, and soon some of the beta changes to the alpha phase. If the brasses are heated up to the temperature at which they become almost or entirely beta, the working of the metal is made much easier. You begin to see now the value to the metallurgist of having a map of the whole region which his metals may inhabit. But although the beta phase is not stable at common temperatures, and tends to change spontaneously into alpha or gamma, it requires a definite amount of time to make these changes, and so, by cooling the alloy suddenly from a temperature natural to beta, above 750° C., we can catch the pure beta form and transport it to conditions where we can study it. Photograph C shows what pure beta looks like, and Photograph B shows the appearance of an alloy cooled from the region "alpha plus beta," where the islands and peninsulas of reddish alpha lie scattered quite thickly on the yellow sea of beta. Photograph D shows the microscopical structure of the alloy into which beta containing between

65 and 40 per cent. copper changes when it is cooled to room temperature. Beta is again the matrix in which the other component has segregated, but the network is a new phase, gamma, whose color is silvery-gray. E is a picture of gamma alone. It is evident that with this phase zinc is getting the upper hand in the combination. The colors of the alloys alpha, beta, and gamma have by this time gradually faded from the red of copper to the colorlessness of zinc.

The other brasses indicated on the diagram as "epsilon" and "eta" are not of commercial importance. Photograph G shows the structure of epsilon of the composition indicated by the second black circle from the right on the diagram. The last circle on the right-hand side is in a region where epsilon and eta exist together. Eta forms the matrix in this alloy, pictured in Photograph H, while the crystals of epsilon can be distinguished from it by the purplish shade of their silvery-gray.

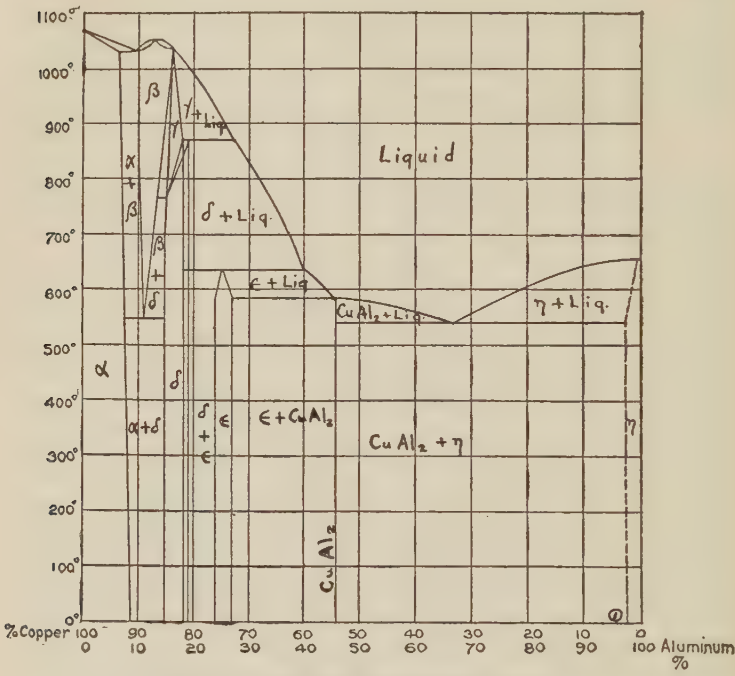
In looking back once more over the diagram as a whole, two curious points are to be noted. The first of them is at the composition 40 per cent. copper, 60 per cent. zinc, where the liquidus and solidus curves touch. This means that an alloy of that composition will melt sharply while the temperature stands constant at 833 degrees, just like a pure metal or a true compound, and it appears that a compound has really been formed, of the molecular composition Cu_2Zn_3. We know very little about the exact mechanism of the formation of inter-metallic compounds, but it is evident that numbers of them exist. Therefore we can

distinguish three different sorts of alloys: true compounds like Cu_2Zn_3; homogeneous mixtures like alpha, which are called "solid solutions" of one metal in the other; and mixtures of two phases which are so clearly shown in Pictures B, D, F, and H.

X-ray spectrum photographs have begun to show within the last few years how the atoms of the two metals arrange themselves in the metallic crystals to form the so-called solid solutions, like alpha brass. Atoms of zinc enter into the copper crystal and actually replace some of the copper atoms. Further research will reveal more of the mechanism of such combinations.

The properties of alloys are in the main derived from those of the two metals which make them up, inclining to the one present in greatest quantity. The melting-points of the brasses descend with lessening copper content from the melting-point of pure copper to that of zinc, with one exception. An alloy which contains a very small amount of copper, lying on the boundary between the eta and the epsilon plus eta fields, is seen from the diagram to melt at a lower temperature than pure zinc. This anomalous behavior is shown by alloys and compounds fairly frequently. The substance which separates at this low temperature is similar to a compound, for under the conditions at which it separates it solidifies at a constant point. It differs from a compound in some technical points, but it is a definite substance and is called the eutectic alloy. It will be observed from the other diagrams that eutectics are formed also by the bronzes and the aluminum bronzes.

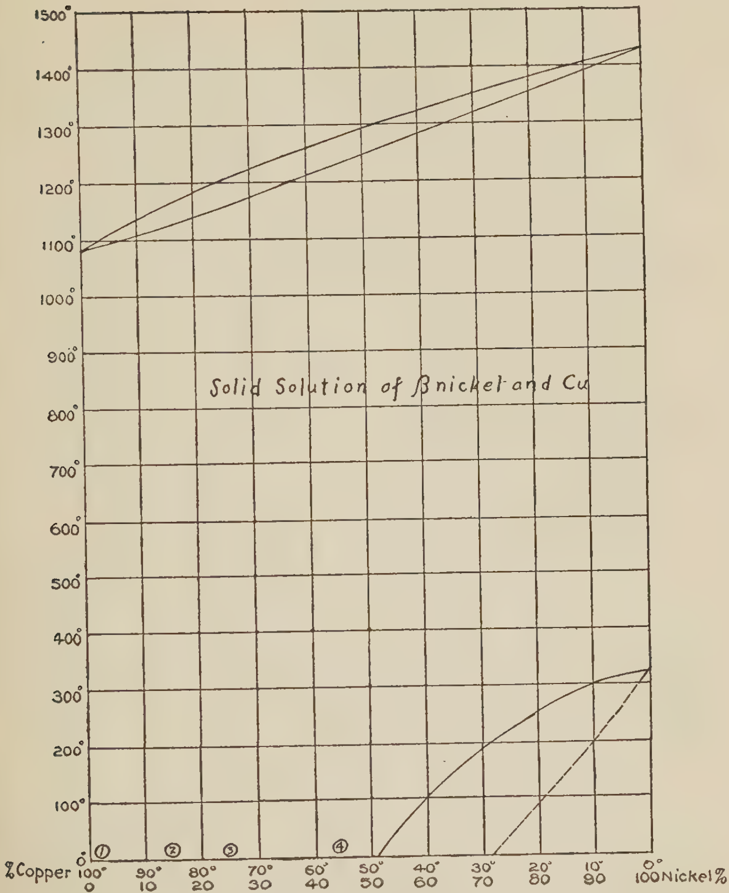
The copper-tin and copper-aluminum diagrams are of the same type as that showing the copper-zinc alloys. In each of these series, it is the copper-rich alloys that are important. Brass, bronze, aluminum-



MAP OF COPPER-ALUMINUM ALLOYS
1. Duralumin

bronze, and copper-nickel alloy are each essentially copper to which has been added an element whose properties add something which improves the red metal for a specific use.

It happens that the alloys at the other end of the diagrams do not have properties that make them par-



MAP OF COPPER-NICKEL ALLOYS

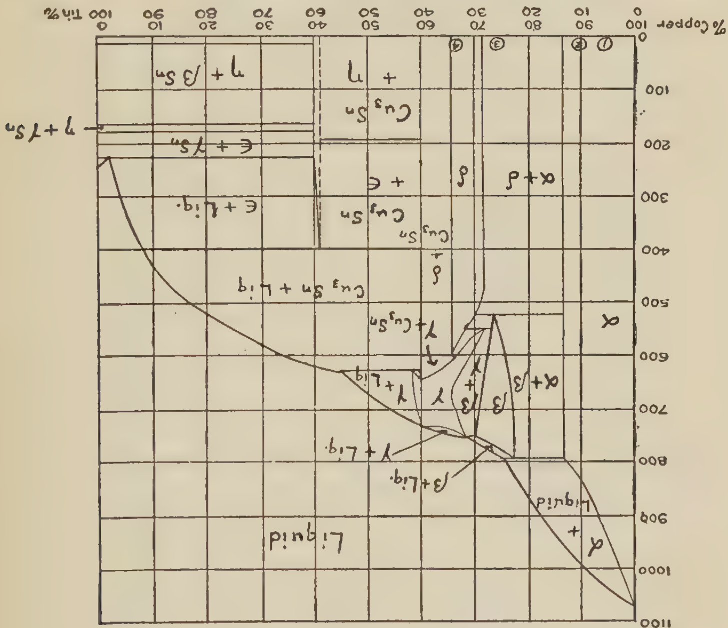
1. Driving bands for shells
2. Bullet jackets
3. Nickel coin
4. "Constantan," used in thermo-couples and elec. resistance

ticularly valuable. If they did, the important ones would contain from about 30 per cent. copper down. It is seldom that a fifty-fifty partnership between metals is very successful. It is a general rule among metals that alloys made up of two metals in about equal proportions are too hard and brittle to be of much commercial importance.

The diagram of the copper-nickel alloys, although it appears at first glance so astonishingly simple, shows several interesting differences from those of the other common copper alloys. It alone of the four here given shows copper associated with a metal of higher melting-point than its own. Nickel's melting-point is more than 300 degrees Centigrade higher than that of copper. It will be noted that the liquidus and solidus curves are continuous between the two ends, with no humps or points. No field boundaries lend complexity to the figure, except at the lower right-hand corner, and that curve means merely a change in the structure of an already homogeneous solid to another homogeneous form. This shows that copper and nickel form a continuous series of solid solutions. Nearly all of the resulting alloys are white. Copper can impart its striking color only when it makes up more than about 85 per cent. of the metal. It must not be thought, however, that all these white alloys are the same. Their structure appears alike under the microscope, but their properties vary as the composition changes. All are very malleable, but, in accordance with the general rule, the fifty-fifty alloys are found to be tougher and harder than are the others.

If the other metal that joins with copper in a part-

nership is unlike it in its physical and chemical properties, the intensity of the effect of its addition is greater in a general way. Thus, tin is more different from copper than zinc, and as a consequence bronze



MAP OF BRONZE

1. Coinage bronze
2. Gun metal
3. Bell metal
4. Speculum metal—formerly used for mirrors

has properties more foreign to copper than has brass. Rosenhain, the English metallurgist, noted also that the intensity of effect is oppositely proportional to the solubility of the added element in the copper, when the solubility is reckoned in terms of relative number

of atoms. The atomic solubilities of zinc, aluminum, and tin in copper are 36, 14, and 6.7, and the increase in hardness and the decrease in ductility caused by an addition of these metals to copper are in the inverse order of their solubilities. Thus, brasses, combinations of copper and zinc, are softest; bronzes, combinations of copper and tin, are hardest and least ductile; and the aluminum-copper alloys lie in between in properties.

Though the brasses are more often and widely used in the world to-day, in point of time the bronzes surpass the brasses. The old pieces of bronze that have been dug out of Egyptian tombs may be nearly twice as old as the most ancient piece of brass. As we have seen, tin was alloyed with copper shortly after copper was discovered and appreciated. Not until early Roman times did zinc appear as a principal and intentional constituent. If you have indiscriminately read the literature of the ancient world, you may doubt the truth of the fact that brass was not used until only a few years before the birth of Christ. In the Homerics, in the Bible, and in the other writings of the early world that have survived you will read "brass" many times. The reason for this is that tin and zinc were not clearly distinguished until much later times, and in those days alloys of copper and tin and copper and zinc were both called brass. Much early "brass" our metallurgists would properly call bronze. The Latin word *æs* signifies either pure copper or bronze, but the Romans did recognize a brass compound of copper and zinc under the name of *orichalcum* or *aurichalcum*. The confusion of brass and bronze was ram-

pant during the middle ages and it even exists to-day, although now a brass alloy is technically but incorrectly called a bronze in commercial usage in some cases when it has a distinguishing and special third metal. Exact knowledge of the copper alloys is of comparatively recent origin. The first nearly complete survey of all the combinations of copper and zinc was only made about twenty-five years ago, while bronzes and the aluminum and nickel alloys have been investigated much more recently.

So extensive are the alloys of which copper is a part that it takes thirty pages of the 1922 annual volume of the American Society for Testing Materials to list their names and compositions. There are separate names for 280 alloys, grouped as brasses because of the predominance of copper and zinc, and there are nearly as many bronzes. Nearly 500 alloys with nickel, aluminum, or manganese as junior partners and copper as the principal part are listed. There are about as many more of gold, silver, aluminum, and other metals in which copper plays a strengthening, but minor, rôle. It would be uninteresting to know the details about all of these. Let us find out about the general classes of partnerships.

As we have seen from our travels in the land of brass, where partnership of copper and zinc reigns supreme, brasses can be of any proportion of the two metals. In commercial circles, however, only the combination containing more copper than zinc proves to be eminently successful. The usual range is from a 90:10 to a 60:40 mixture, but most successful and useful are the alloys with from 80 to 60 per cent. copper.

"Red metal" is the name given a rich copper combination of 90:10, and the alloys of this general proportion are used as substitutes for gold in cheap jewelry; 80:20 brass is called low brass and sometimes "bell-metal," although the latter term generally means a bronze that is better suited for bell-making than the brass. The favorite proportions of brass for making tubes and wire is 70 per cent. copper and 30 per cent. zinc, while standard sheet-brass is a 66:34 combination, which is also the alloy most frequently used for castings of brass. Brasses which contain more than 67 per cent. copper are made up entirely of alpha brass and are sufficiently ductile so that they can be worked cold, but great care must be used in annealing so that strains caused by the working will not be left in the metal and cause a failure in later life. The brasses with lower amounts of copper, ranging from 55 to 63 per cent., are used in operations that require hot rolling or extruding. The ductility of these brasses is very low when they are cold. If you remember, brass of this composition when cold is composed of both alpha and gamma brass, according to the constitution diagram of brass. When it is heated, at one temperature interval it changes to homogeneous beta brass which is easy to roll and work. The approximately 60:40 brass has a full yellow color and is sometimes called yellow metal. More often it is named after G. F. Muntz, who invented it in 1832 in England, or, instead of "Muntz metal," "patent metal" is the term used sometimes for the same reason. Muntz metal is a very useful and reliable alloy under most circum-

stances, though it has one failing. In some sorts of water, particularly water that is acid, it will corrode.

For sea use, brass usually can be protected against disintegrating if a little of the capital of tin is called into the partnership and the working arrangement is made ternary instead of binary. The firm name of such an arrangement of about 61 per cent. copper, 38 per cent. zinc, and 1 per cent. tin, is "naval brass." A little tin entering into virtually any brass usually makes it a little better. Several other names are applied to brasses with a small amount of tin used in marine work. Among these are "Tobin bronze" and "pivot disc bronze." Tobin bronze contains from 59 to 63 per cent. of copper and from ½ to 1½ per cent. of tin; the remainder is zinc. As the composition shows, these so-called bronzes are in reality brasses. This is only one example of the present-day confusion in metallurgical terms. The most flagrant case of mislabeling is "manganese bronze," which is not a bronze nor does it contain manganese as an important constituent. The manganese part of the misnomer arises out of the use of ferromanganese or pure manganese as the lawyer or deoxidizer attending to the expulsion of undesirable oxygen from the partnership and making the founding of the firm easier. The "bronze" part simply came from starting wrong, and the alloy has not been able to overcome the incorrect name. The compositions of manganese bronzes vary but may be listed as about: copper 58, manganese 0.3, zinc remainder, with small quantities of tin from 0.5 to 1.5 per cent., iron from 0.8 to 2 per cent. aluminum,

and lead sometimes amounting to several parts. Some true copper-manganese alloys are used, especially as stay-bolts for boilers in European countries. Tests of copper with additions of 6 to 8 per cent. manganese have revealed promising qualities.

Lead added to brass improves its machining properties and is very important in many industries. Lead does not show the same compatibility when mixed with copper and zinc that those two metals accord each other. The particles of soft lead stand off in globules and refuse to become intimate. The resulting solid is made up of lumps of lead scattered through the brass. The mixture, shown in the photomicrograph, looks like a piece of Schweitzer cheese. The cheese is the brass and the "holes" are filled with lead. Typical lead brasses are composed of 60 to 63.5 per cent. copper, 35 to 33.5 per cent. zinc, and 2 to 3.5 per cent. lead. Tin sometimes appears as a fourth component of lead brasses.

Iron is often added to brass in small quantities to add to its strength, hardness, and toughness, as it does not destroy its ability to be worked, either hot or cold. Delta metal has a composition of 55 to 65 per cent. copper, 43.5 to 30 per cent. zinc, and up to 5 per cent. iron. Aitch's metal, a similar alloy, has a 56:41.5:1 composition. Fourth and fifth members of the brass firm are added in some cases to obtain special qualifications. Vanadium enters into a special Victor bronze: 0.03 per cent. vanadium, 58.6 per cent. copper, 38.5 per cent. zinc, 1.5 per cent. aluminum, and 1 per cent. iron.

One of the most common examples of a bronze is the "copper" that you probably have in your pocket. Since early in the history of the world bronze has been a favorite coinage metal, and to-day millions of coins in all parts of the world are made of it. The composition of the United States one-cent pieces is 95 per cent. copper and 5 per cent. zinc and tin, the relative quantities of tin and zinc varying in different batches of penny materials. If coinage bronzes are not all copper and tin, 1 or 2 per cent. zinc is often added, and the French coins contain some iron to make them hard. Gun-metal is the name that still clings to the alloy of about 90 per cent. copper and 10 per cent. tin that was once used in the manufacture of artillery. In most cases some zinc is added in making gun-metal. The government specifications call for 88 per cent. copper, 10 per cent. tin, and 2 per cent. zinc, and this metal is known as government bronze. "Bell-metal" is the name applied to the bronzes used in casting bells; they may range from 10 to 25 per cent. tin. The composition of statuary bronze varies over a wide range, and zinc and lead are added to give it better casting qualities and enhance the valued patina that statues take on with age. Either the zinc or tin in any one alloy should be below 2 per cent. when the composition is: copper, 88 to 95 per cent.; tin, 2 to 10 per cent.; zinc, 0.5 to 10 per cent.; and lead up to 2.5 per cent. A bronze called "speculum metal" that takes a very high polish has a tin content of about 30 per cent. and because of its white color and surface was used as mirror material before looking-glasses

were perfected. Phosphor bronze, unlike the similar sounding brass, manganese bronze, is a true bronze, and, while the phosphorus that gives it its name acts as deoxidizer and by its cleansing action produces more fluid metal and sounder castings, it also enters into the partnership. By the use of phosphorus, strength of bronzes can be increased a third without materially lowering the ductility, because of the removal of the oxides. Phosphor bronzes contain in their composition less than 1 per cent. of phosphorus in most instances.

As material for bearings, modified bronzes are used extensively. Bearing metal must stand three tests: it must wear well, it must "give" sufficiently to carry the load evenly, and it must be strong enough to resist the weight. Copper-base metals are the strongest bearings in general use. Originally they were made of a simple alloy of copper and tin, but lead was found to add to the plasticity of the bearing. The soft metal is imbedded in a matrix of bronze dendrites forming a cushion.

Standard bronze bearing metals contain from 5 to 30 per cent. lead, and, although the results are not so good, zinc is often added as a fourth component. In making machinery parts that are exposed to corrosion or that wear on each other with considerable friction, bronze is widely used. In the case of parts that rub, the one that is most easily replaced is made of bronze and allowed to take all the punishment. Here is how copper is used in various compositions of machinery bronze:

	Compositions				
	Copper	Tin	Zinc	Lead	Antimony
Eccentric rings	84.0	14.0	2.0		
Dense alloy for pump-bodies and valve-boxes	88.0	10.0	2.0		
Whistles for locomotives	80.0	18.0	2.0		
Same with somewhat duller sound	81.0	17.0	2.0		
Stuffing-boxes, valve-balls	86.2	10.2	3.6		
Screw-nuts for large threads	86.2	11.4	2.4		
Piston-rings	84.0	3.0	8.5	4.5	
Distributing slide-valve	82.0	18.0	2.0		
Alloy for mathematical and physical apparatus but slightly subject to changes in temperature	82.0	13.0	5.0		
Alloy for more delicate weights, balances, and mathematical instruments	90.0	8.0	2.0		
Propeller blades and boxes	57.0	14.0	29.0		
Paddle-wheel pins	76.8	17.4	5.8		
Cog-wheels	91.0	....	9.0		
Special highlead bronze	70.0	5.0	....	25.0	
Babbitt, tin-base					
Babbitt for motor	3.7	88.9	....	....	7.4
bearings	1.0	50.0	....	38.5	10.5

Alloys are now made with copper that are very similar to the copper-tin bronzes that have been used for centuries, yet the like of them could never have been known if a young American chemist named Hall had not discovered a fairly cheap method of separating aluminum from its ores electrolytically. Aluminum and copper compete to a small extent in the electrical field, but as partners in the same alloy they get along very well. Aluminum bronzes, as copper-aluminum alloys are called despite the fact that they contain no tin, were first produced in 1885 when the recently electrolyzed aluminum was absorbed into copper. The usual amount of aluminum added to copper is from 3 to 10

per cent. But the possibilities of the general partnership of copper and this newer metal have not been investigated as thoroughly as they might be, and we may expect to see a greater use for it in the future. Copper-aluminum alloys have strength, ductility, and resistance to corrosion, and can be worked both hot and cold, but they are costly, and difficult to melt and cast, owing to the liking of aluminum for oxygen and to their shrinkage. As junior instead of senior partner copper also enters into alloys with aluminum, forming from 1 to 5 per cent. of such mixtures, and often working in conjunction with magnesium, manganese, nickel, or zinc.

Among the oldest alloys known to man are those of copper and nickel. They may even antedate or equal in age the better-known brass. Bactrian coins containing 77 to 78 per cent. copper and 22 to 23 per cent. nickel date from 235 B. C., and their composition is almost identical with the modern nickel coinage alloy. Despite its antiquity the pure copper-nickel partnership has not come into the prominence that its unusual properties should give it, although during the war its service on the battle-front served to stimulate interest in what it can do. As we learned when we surveyed the map of the copper-nickel partnership, these two metals dissolve into each other in all proportions, and unless there is more than 85 per cent. copper the front put up by the partnership is the same as nickel's color. Some of the compositions of copper-nickel alloys now in common commercial use are: cupronickel, containing 2.5 per cent. nickel, used as

material for driving-bands of shells; 15 per cent. cupronickel, used largely for bullet-jackets and by the United States navy; nickel-bronze, or coinage bronze, used for baser currency and containing 25 per cent. nickel; copper-nickel, containing 50 per cent. nickel, used for remelting in the manufacture of copper-nickel alloys; constantan, used as one element in the construction of thermocouple pyrometers and also as electrical resistance wire, containing 45 per cent. nickel. A natural alloy in which copper plays an important part is monel metal. This alloy consists of 67 per cent. nickel, 28 per cent. copper, and 5 per cent. of iron, manganese, silicon, and other metals. It is produced from the Sudbury ores in Canada that have that composition after smelting and refining. Despite the fact that nature compounded this alloy in the earth many epochs ago, it was only in 1905 that it was first brought into metallic partnership by man and put to work in his service.

Another nickel alloy that contains a major amount of copper is of very ancient origin and was known to the Chinese under the name of "packfong," or white copper. In the course of time this partnership of copper, zinc, and nickel acquired the name of "German silver," but during the War our patriotic citizens came to the conclusion that it was too useful and doing too valiant service in the War to wear a Teutonic name. So it was changed to nickel silver, which is only half right at that. A committee of the American Society for Testing Materials has suggested that the name be changed to "nickelene" to deprive the alloy of its de-

ceptive label, but it seems likely that users of the metal will continue to prefer the richer sounding name of nickel silver. In truth, it is a nickel brass. The varieties of nickel silver are legion, but their compositions will vary usually within the following limits: copper, 52 to 80 per cent.; zinc, 10 to 35 per cent.; and nickel, 5 to 30 per cent. The proportions in commercial use are:

Material	Nickel	Copper	Zinc	
Cutlery and knife stock	15–25	55–65	14–20	0.5–1.5 Iron
Key stock	8–18	55–65	15–35	1–2 Lead
Jewelers' wire	5–25	53–63	25–32	...
Brazing solder	8–20	35–40	40–55	...
Watch-case metal	10–28	55–65	16–30	0–1 Lead
Spoon and fork stock	10–20	57–66	20–30	...
Platers' bars and cores	5–25	56–70	18–24	...

Copper, nickel, and zinc are combined in many different proportions to form nickel silver, but there is a separate name for nearly every different composition. A few of the aliases of the copper-zinc-nickel partnership are: extra white metal, white metal, arguzoid, best best, firsts or best, special firsts, seconds, thirds, special thirds, fourths, fifths, for plated goods, alfenide, alpakka, amberoid, argentan, argentan solder, argentin, argiroid, argozoil, arguzoid, argyrolith, aterite, carbondale silver, Colorado silver, China silver, craig gold, electroplate, electrum German silver, Keens alloy, Lutecin. Maillechort, Markus alloy, neogen, Nevada silver, new silver, nickelin. These alloys are largely used as substitutes for silver and as base metals for plated silverware of all sorts. As their color is very similar to that of silver they can per-

form this task well. Lead often becomes a fourth member of the alloy when the metal is to be machined during manufacture.

If I tell you that copper is used in the manufacture of jewelry, you will probably first think of the five-and-ten-cent store and its array of baubles. In that brass copper is contained, to be sure. But in the proudest wedding-ring and the most valuable brooch there is some copper. Gold is not usually 24 carat, that is, 100 per cent. pure. Some copper is added to take the gaff of every-day wear. Very rich gold contains only copper as an alloying metal, but those below 18 carat also have silver added. The universally accepted formulæ for the various alloys of gold, expressed in parts out of 24, are:

		Parts of	
	Gold	Silver	Copper
Carats (K.)			
22	22	0	2
20	20	0	4
18	18	1	5
16	16	1	7
14	14	2	8
12	12	2	10
8	8	3	13
6	6	4	14

Silver as well as gold appreciates copper's superior wearing qualities, and copper is added as a hardener to silver for use in jewelry and plate. The famous sterling silver is made up of 7.5 per cent. copper and 92.5 per cent. silver, while enamelers' silver is slightly richer, with only 6.5 per cent. copper.

In the literature of the Romans and in classical writings, Corinthian bronze was loudly extolled for its

great excellence and beauty. This statuary metal was so artistic and beautiful that the Romans could hardly believe that it was compounded out of mere base metal, Pliny, carried away by his laudations, states that the alloy was discovered by the Romans at the sack of Corinth, when vessels of gold, silver, and bronze had been accidentally melted together during the burning of the city and produed a golden bronze. It happens however that the siege of Corinth occurred in 146 B. C. and the excellence of Corinthian bronze had been recognized long before that time. Moreover modern metallurgists know that no addition of gold and silver to any copper-tin alloy will cause it closely to resemble gold; and, though they do not know the exact composition of the bronze of which several statues are said to have been cast, they believe that the same imagination that deduced that the beauty of the Corinthian bronze was derived from being cooled in the water of the fountain of Peirene also conferred upon the alloy the beauty that the Roman accounts praise. Was not the ancient praise simply the recognition of the qualities that cause us to cast our monuments in copper alloys?

Copper-containing alloys are usually beautiful and always good and useful. They work their way through the world that we may dance to the tinkling of brass and pay our way in bronze and copper-gold.

CHAPTER IX

PUTTING COPPER AND BRASS TO WORK

Copper has many lifetimes of work to do in the world when once it has been brought to the refined metallic state. Before it can enter into the active service of man it must be put through a series of rigorous shapings that will fit it for the different lines of usefulness that it will engage in. During this period it must meet other metals and arrange the permanent partnerships that are necessary in many cases. It must go through the treatments that will enable it to withstand the hardships of commercial life.

Like most of us, copper does not have a chance to choose the particular kind of work it is to do. Only when its impurities bar it from the electrical field are its possibilities limited, and even then there are all sorts of interesting alloys it can help to form or many kinds of castings that it can fill. The destiny of a piece of copper begins to be shaped when it flows out of the refining furnace after electrolysis into a particular form of mold and becomes wire bar, ingot, or cake. If it finds itself with the points of a wire bar it is able to feel rather sure that it will soon be a copper wire. If it is cast into a humpy ingot it can predict that it will become a copper casting, take up with zinc and become brass, or possibly join with some other metal such as tin or aluminum. The copper in a cake

is able to guess with great accuracy that it will find itself rolled out into a sheet or plate, eventually to appear on a roof or in a copper utensil. The chances are a little better than one to one that a particular gob of copper will be a wire bar and a potential conveyor of electricity. This is the proportion of copper cast in different forms in 1920, as given by the United States Geological Survey:

Form	Percentage
Wire bars	52.53
Ingots	27.42
Cakes	12.80
Cathodes	2.44
Other forms	4.81

It is rather difficult to say definitely how much copper is used in each class of fabricated material, and the estimates made are very approximate. But the copper marketed domestically in 1919 was apportioned roughly as follows:

Use	Pounds	Percentage
Electricity	500,000,000	47.8
Brass fabrication	300,000,000	28.6
Straight copper fabrication in mechanical goods	150,000,000	14.3
Bronze, German silver, and other alloys	22,000,000	2.1
Brass for remanufacture, mill cuttings and shavings	75,000,000	7.2

If the copper used by the world in one year were parceled out equally to every inhabitant of this earth, each person would have about 19 cents' worth, 1.3 pounds. The semi-savage on a tropical island would wonder what to do with all this metal, for he is familiar with it only in ornaments or the simplest sort of

utensils. He would be content for a lifetime with only a few ounces. And, if such a distribution were made, there would be a serious and disastrous shortage of copper in America and Europe. The fact is, of course, that, although the average yearly per capita consumption of the world is 1.3 pounds, the bulk of the use is concentrated in the more advanced countries of the world. Going back before the de-civilizing World War, we find that the United States in 1912 used 7.7 pounds of copper per capita, while the vast expanses of Africa, Australia, and Asia combined used only about eight thousandths of a pound per capita. Europe used about 3.1 pounds per person, while the two Americas combined have the high record of 6.2 pounds.

A truly wonderful statistical story is told when the consumption figures for the last quarter of a century are studied. Between 1897 and 1912 the world's consumption of copper increased 139 per cent., and by continents the increase was: Europe, 105 per cent.; America, 218 per cent.; Australia, Asia, and Africa, 233 per cent. Year after year before the War, the consumption of copper in the United States increased on the average of 13.5 per cent. a year. As is natural, these increases over sixteen years are largest in the undeveloped countries that were expanding at a great rate. If you are interested in the growth of copper use in the European countries during that period, here are the data:

Country	Percentage of Increase
Italy	370
Austria-Hungary	182
Russia	163
Germany	158

Country	Percentage of Increase
Miscellaneous European countries	150
France	94
England	44.5

The rapid expansion of the mechanical age is the cause of this increase in the use of copper. Machinery is replacing human and animal muscle, metal is substituting for wood, creations of the mind are softening the callouses of the hands of men. And during the last twenty-five years more and more machinery has been electrically driven. Electrical expansion means copper expansion.

Iron has been considered the symbolic material of the new mechanical epoch. We are told that we are in the Iron Age. But iron must share its glory with copper. Two steel rails will continue to carry the locomotive, but the steel will be paralleled by a strand of copper and the driving power will be electricity. The electrical era is partly here and coming fast; it is time to hyphenate the material first name of the era and call the present the "Iron-Copper Age." The comparative consumptions of iron and copper trace this transition into the present age. From 1880 to 1885 the world produced one ton of copper to every 104 tons of iron. From 1901 to 1905 the ratio had dropped to 1 to 80, and it decreased uniformly until the outbreak of the war. For the year 1916, one ton of copper was produced for every fifty-three tons of iron, showing the greediness of war; more copper is required in modern warfare than in modern industry.

Rapid as the increase in the use of copper has been, we must look forward to much greater demands in the future. In Asia about 900,000,000 people live who use

only minute quantities of red metal. Modern inventions have not reached them; the principal Chinese use of copper is in their coins. If the Chinese should adopt modern inventions in the next twenty-five years to the extent that the Japanese have in the last quarter of a century their use of copper would add greatly to the world's demand. If Asia reached the point where its per capita consumption was only one tenth that of the United States, its demands would exceed ours by about 130,000,000 pounds a year, and if its use should reach the figure for the present world average consumption it would be consuming nearly 1,117,000,000 pounds a year. Suppose that every country of the world used as much copper each year per person as the United States does at the present time. The total world's requirement of copper would be enormous. Figure it out for yourself; the numerals are nearly too fantastic to write.

There is a real difference between the amount of copper that a country consumes, the amount that it produces, and the amount that it manufactures. While the large consuming countries are also the large producers, they also manufacture the metal used by many of the smaller nations that have not yet reached the point of having their own copper and brass fabricating industries. Just as some of the smaller countries send their youth to this country for training, so they may ship us their ore or their copper and receive in return the same metal fully prepared and ready to go to work in their growing industries. Before the war Germany led the world in copper manufactured per capita with about 8.5 pounds, despite a lower per

capita consumption than America, and a very small per capita production. Most of the copper manufactured in Germany necessarily came from America. The United States was second in copper manufacture per person at the rate of about 8.1 pounds per year; the United Kingdom was third with about 6.7 pounds; and France was fourth with about 5.8 pounds.

Turning these few pounds of copper per person, these millions of pounds of copper per year, into products that go to the ends of the earth and penetrate into the heart of the home, is a large industry demanding many factories and many workmen. We have followed copper through its first stages of manufacture, in the mine, reduction-plant, and refinery; we can now see it turned into the standard kinds of wire, plate, sheet, pipes, and rods, both copper and brass, that are used in places to do their part in the work of the world.

Every wire must first be a rod before it metamorphoses into final form. The wire bar is the raw material used in the development of a copper wire. In the reduction of refined copper to wire or rod the processes used are principally physical, unlike those that separated copper from its ore. The wire bar is rolled into wire.

A hundred wire bars are held on the table that feeds them regularly into a heating furnace, fired by fuel oil or other burners at the exit end of the furnace. A hundred bars enter and leave the furnace each hour under the urge of a compressed air pusher on the feeding end. The blushing bars, red-hot, proclaiming a temperature of about 750 to 800 degrees Centigrade, are picked up in tongs and carried to their first squeez-

ing experience. The first groove in the rolling-mill is called the "roughing mill," and it is. Heavy steel rollers pick the copper up and do their best to squeeze out some of the wire bar's fatness. When the first set of rollers has finished with it, the bar is dropped to a lower set of rolls which, after they have done their elongating, send it back to the other side of the machine. Back and forth the glowing bar travels, and as it passes through about seven reducing rollers it gets thinner and thinner, lankier and lankier. From the roughing mill the bar passes to the intermediate and finishing mills. In these it is rolled still more, and by this time it is so long and thin that it will not automatically pass itself from roll to roll but must be helped by a man who catches its end in a pair of tongs. When the wire bar has passed through the last roll and has finally become a rod, from one fourth to five eighths of an inch in diameter, it runs through an iron pipe to the coiling machine where it is wound on a reel. The finished coils are black with oxide formed while the hot metal was exposed to the air during the rolling process, and this is removed by "pickling" in a dilute solution of sulphuric acid. The coiled rods are then ready to be drawn into wire.

The drawing of the rod into wire consists of pulling the cold rods through a series of dies of decreasing size and thus continuing the reduction of the diameter of the wire and increasing its length. For the larger size wires, the drawing is done through only one die at a time until it is finished, but with the smaller sizes the wire is taken at the same time through several dies grading downward in size. The wire drawing

machine has a series of drawing rollers, each of which pulls the wire through one die and passes it to the next. Each roller and the coil at the end of the process are geared so that they will take up the extra length of wire created by the drawing process. The rollers at the end of the drawing are speedier than those at the beginning. The small circular dies used for drawing are made of chilled cast-iron with a tapered hole. They are reamed to exact size by hand, and when the continual wear of the wire has made the hole larger by one thousandth of an inch, the usual variation of diameter allowed in all small wires, the die is reamed out to the next larger size and used again. A die will hold its size within this limit while about four miles of wire have been drawn through; then it must be given a larger opening.

When wire bar was turned into rod the copper was hot and plastic; it did not change its hardness, ductility, or strength appreciably. But when it is drawn cold it becomes hardened, stresses are set up within it, and it loses its pliability. The hardening occurs about in proportion to the reduction in diameter. This is quite satisfactory if hard wire is wanted, but if hardness is a disadvantage something must be done about it. To obtain soft wire, the hard copper is heated up until it just begins to get red, about 600 degrees Centigrade, and then allowed to cool. The heating relieves all the stresses and strains of the cold-drawn hard wire and leaves it untroubled, soft, and easy to bend. This process is called "annealing." The properties of red metal put through this treatment, unlike those of steels and some copper alloys,

do not seem to be affected one way or the other whether the cooling takes place quickly or slowly.

Often a wire intermediate between hard and soft is desired, and this is manufactured by a novel method. As the amount of hardness varies with the work done on the wire in drawing, medium hard wire is produced by drawing the rod to a certain size which, after being annealed, will require just the necessary amount of further drawing to produce both the size and the degree of hardness specified.

Copper wire can be drawn as fine as one thousandth of an inch in diameter, and a one-fourth-inch soft wire will stand a cold reduction to about one thirtieth of its sectional area in the dies.

When trolley-wire, which must be furnished in long lengths, often a mile, is made, many rods must be joined together, and this is done by brazing the rods before drawing with solder of silver, the only metal that surpasses copper in electrical conductivity. Ordinary round trolley-wire is drawn through cast-iron dies but for grooved, figure eight, and other shapes the dies are made of steel, carefully punched, sized, and hardened.

In another process heated plastic metal is squirted into rods or wire. A hot billet is placed in a large machine and a great plunger, hydraulically operated, extrudes it through a die as easily as you squeeze out the allotted half-inch of tooth-paste every morning. This extrusion method is used for wire and rods of brass as well as for copper. This is the method used for the shaping of special forms, angles, T-bars, moldings, and other such designs, which are finished to di-

mension by one or two drawing operations. Many such special shapes are cut up and become machine parts and accessories.

The cast cakes or slabs of copper that are destined to become sheet-copper go through about the same experiences as a wire bar. Hot rolling usually flattens the sheet partially down to size, and then it is finished down to size by rolling cold, with or without intermediate annealing depending upon the properties desired.

At one time the making of sheet copper was the first-step in the manufacture of copper tubing. The village coppersmith took a hand- or machine-rolled sheet, shaped it around a core, and fashioned it into a seamed tube, secured either by the crimp or by rivets. Such slow and often unsatisfactory methods have now largely given place to modern machinery that will pierce and draw down a solid or hollow cast billet and make it into a tube, or that will extrude a copper tube through a die. Cylindrical solid billets from the refinery that have been turned down on a lathe to remove surface impurities and imperfections are used in the piercing, or Mannessmiann, process. After a billet is heated to about 850 degrees Centigrade, it is placed in the piercing mill where it encounters a steel point carried on a long rod. It is forced over this, rotating between the rolls that confine it and at the same time give it a powerful forward motion. The billet is thus shaped into a thick walled tube as yet somewhat irregular in size. Its manufacturing experience is concluded in somewhat the same way as that of a wire. The pierced billet is sent to draw-

benches and pulled through dies at the same time that its interior diameter is shaped and made regular by inside plugs or mandrels. The sizes of the die and plug are so proportioned that the outside of the tube is reduced in diameter more than the inside. The tube is made smaller and the walls are made thinner. Drawings and annealings are alternated as in the case of wire, and, when at last the shaping process is over, the tubes, tempered, cleaned, and straightened, are tested and sent out into commercial life.

The piercing method of tube-making is rather strenuous. It is a hot-process method and can only be applied to those alloys or metals that can be readily shaped in that way when hot. Happily most of the brass tubing in use to-day is manufactured by this piercing method, which is the most economical. But for alloys that will stand cold-process treatment and will not stand the hot process, a method of tube-making known as the cast-shell method or sand-core process can be used. Instead of a solid billet, a hollow one is cast with a sand core that can be easily removed after solidification. The result is a seamless tube or shell that is drawn in exactly the same way as a pierced billet to form a finished seamless tube. When tubes of large diameter and thin wall are required they are sometimes fashioned out of a disk or blank of sheet copper by piercing its center and then gradually shaping it. This blanking method is applied to metals and alloys that will not stand the hot process of manufacture, and it has the added advantage of allowing the blank to be inspected for surface conditions before it is shaped into tubes.

When tube manufacture is being described, do not think only of the round tubes that are used as condenser-tubes or as pipes in our houses, but visualize also the odd shapes that are useful in the construction of store-fronts, skylights, metal trim, and window-sash. Brass and copper of special shape are fashioned by the drawing process in a manner similar to rods, wires, and tubes.

One sort of seamed tube in appearance closely approaches the seamless variety. If the edges of a tube shaped from sheet-metal are brazed together, the hard solder composed of copper and zinc closes the seam so well that it becomes virtually invisible. Brazing, soldering, and riveting of copper have been favorite methods of joining two copper rods, wires, or sheets together, but welding, which makes more secure joints, is now in use by the three common methods. Copper may be welded by the ordinary smith-welding process, using borax or borax-mixture flux. The oxyacetylene blow-pipe, although it will not cut copper as readily as iron and steel because of copper's capacity to conduct away heat, will join two pieces of copper together in their own molten metal if a large pipe and lower-temperature flame are used. Any of the electrical methods can be used, although in arc welding two or three times the power is required for a copper weld than for iron. Electric welding is another case of copper aiding itself. There was once a time when all joints of copper wire were hard-soldered with brass and only roughly filed, not drawn. The wire that was joined in this way was made by shearing from rolled sheets of copper very narrow strips of nearly square

wire, which was rounded by drawing through rough dies. This process was extremely unsatisfactory because of troublesome slivers that remained attached to the wire, and because of the bulkiness of the joints. When in the eighties early dynamos were being constructed it was impossible to obtain suitable wire of considerable length because of these deficiencies in manufacture. Earlier Dr. Elihu Thomson had noted the possibilities of changing a high voltage current of moderate amperage to immense quantity of low voltage, thus creating enough heat at the junction of two wires to fuse or weld them together. This scheme perfected is the Thomson method of resistance welding. When this common operation of to-day was applied to joining copper wire the welds were so secure that they could be forgotten and the wire could be drawn to perfection and the earlier defects eliminated. All copper welds are usually hammered in order to break up the cast structure and restore the strength and ductility of the welded portion.

The most ancient of the processes for manufacturing copper is one that is practised only to a limited extent to-day. Primitive man hammered out his knife of red metal with a cudgel of stone; to-day, instead of slow and laborious shaping under the blows of the hammer, the rollers of the mill shape and squeeze copper into commercial articles. If a hammer is used, it is so large that one blow will punch out a finished product from a rolled copper sheet; only in art centers and in the less advanced countries of the world is the crude method of shaping copper by a series of tiny indentations practised now. The other import-

ant method of shaping copper that was used by the ancients is in extensive use to-day. Although molds of stone have given way to those of steel and special molding sands have replaced haphazard earths, although advanced methods of keeping the copper pure and at the right pouring temperature have been evolved, casting is much the same procedure that it was four or five thousand years ago.

Although copper is not flowed into its final state as often as the partnerships that it forms, castings of red metal find thousands of uses in this world. Finished castings of copper are used in the making of electrical apparatus, and rough castings are often the first steps toward drawing pipe. Being cast is usually not a new experience for copper. Virtually all copper at one time in its life undergoes the experience of running into a metal mold after it has been turned into blister copper or after it has passed through the electrolytic refining process. But most of the copper that flows into the form in which it is used in everyday life is poured into sand molds, usually damp, or, as the molder would say, "green." Because of the oxidation of the metal and the likelihood of the formation of blow-holes owing to the giving off of absorbed gas during solidification, pure copper is more difficult to cast than its alloys. If a reverberatory furnace, such as was used in its refining, melts the copper, the poling process can be used to purify oxidized metal. But if a crucible is used care must be taken to prevent overoxidation, as manipulation of the copper is impossible. Often a layer of charcoal or a handful of common salt is sprinkled upon the metal to form a bar-

rier to the air. With good workmanship and care, successful copper casting can be obtained without the removal of oxygen that has found its way into the melt and combined with some of the copper. But modern practice favors the use of some substance, added to the molten copper before pouring, that will carry off this oxygen. Affinities of oxygen, such as phosphorous, silicon, calcium, boron suboxide or carbide, zinc, titanium, and magnesium, not only remove this element but prevent the absorption of gases which would later cause trouble through blow-holes during solidification. Ideally, only enough of the deoxidizers are added to complete their job efficiently and then go off without a trace. Practically, as is often the case, this can not be done. Some of the added element stays with the cast copper and affects its properties. Most deoxidizers lower copper's electrical conductivity, and this is a disadvantage, as many castings must serve as current carriers. Phosphor copper, containing about 15 per cent. phosphorous, is a common deoxidizer that is added to molten copper in the proportion of about 1 or 2 per cent., and, though phosphorous lowers electrical conductivity, it hardens the copper. Zinc as a deoxidizer mimics phosphorous's bad points, but silicon, introduced through the addition of silicon copper containing 10 per cent. silicon, does not affect either mechanical or electrical properties as markedly as phosphorous and zinc. Silicon copper and boron carbide, another deoxidizer which gives excellent results, can be added to excess without danger, as they will not remain in the copper but will go off with the dross that is formed on the top of the molten metal.

No matter how highly oxidized copper may be, and how unsatisfactory its tensile strength and ductility may be because of excess oxygen, several remelts with the use of a good deoxidizer will rejuvenate it and make it better than or equal to new metal. When cast copper, or, for that matter, any metal, is being dealt with, one unfailing characteristic must be reckoned upon. If you pour metal into a mold one foot long, you will obtain from it a casting only 11¾ inches long. In passing from the molten to the solid state, the metal contracts 1.42 per cent., and this volume change must be allowed for by every one concerned with copper casting, from the designer to the machinist.

It is true that some of the copper ingots remain copper even after their metamorphosis into other forms, such as castings, but many more of them once melted never see the pure copper state again. Most of them find themselves forced to associate with zinc to form a very successful and useful combination, brass, and a large industry has grown up to care for this association. Smaller numbers of copper ingots form partnerships with tin, aluminum, nickel, gold and silver, and other metals whose intimate secrets we have learned earlier. But the methods of forming metalliferous combinations are very similar. If we look into the details of arranging the partnership, brass, we shall have a fair general idea of the methods of manufacture of the other alloys.

In seniority, bronze outranks brass. So early did the combination copper and tin come into use that recorded progress of man had not yet begun. Brass is much more youthful, but even so it certainly dates

before the Christian era. The brass partnership until only a little over a hundred years ago and less was brought about by the coöperation of a compound of zinc with copper, not metallic zinc itself. Calamine, a hydrous silicate of zinc, and, perhaps, a zinc carbonate, smithsonite, which is also occasionally called calamine, were the substances that were used as the source of the zinc of early brasses. During the sixteenth and seventeenth centuries, metallic zinc, probably known in the Far East before Europe had isolated it, was imported into Western Europe under various names: tuteneque, tuttanego, calaëm, and spiauter. From the last term the commercial name of metallic zinc, spelter, has descended.

There was no particular reason in the days of small production why brass should be made from spelter rather than calamine. There were indeed economic arguments in favor of the survival of the admittedly inexact, yet successful, calamine brass. And it did persist in commerical practice long after the first brass was made in America. If the substitution of metallic zinc for calamine is excepted, there is little difference in the fundamentals of brass-making to-day and several hundred years ago. Proportions have been standardized, machinery has been perfected, production methods have been made more efficient; that is about all.

In 1645, Joseph Jenks, a native of Hammersmith, near London, came to Massachusetts as principal workman and machinist for John Winthrop, Jr. He is believed to be the first founder of the white race who worked in copper and iron on the western hemisphere. Three years later copper deposits were dis-

covered, and Governor Endicott brought smelters and refiners from Sweden and Germany. During the fifty years following 1725, Casper Wistar and his associates hammered out stills and kettles from brass and copper in Philadelphia, and they also manufactured and molded brass. And before the Revolutionary War it is certain that brass cannons were cast in America's first capital city. Brass buttons were the first products of the American brass industry which has arisen in New England. The people of Naugatuck Valley were making pewter buttons when superior brass buttons came into vogue. They were forced to manufacture the new buttons or lose their trade. Power, labor, and the other necessities of brass mills were present there, and this combination of conditions caused the industry to flourish, so that even now Connecticut is the largest producer of brass in this country. Silas and Samuel Grilley established a brass button business at Waterbury, Connecticut, in 1802 and twelve years later Silas joined Abel and Levi Porter from Southington and Daniel Clark in making buttons from sheet-brass. This partnership through uninterrupted growth and development grew into the Scovill Manufacturing Company of to-day. In fact, the brass industry can point to three great American companies that are over a hundred years old, a record equaled by few industries in America. The brass industry of this country in its initial stages was imported from England as was most of early New England. It was not until the Porters came to America that brass-making by direct fusion of copper and zinc, according to the English process then only twenty years old, was

introduced, and brass was rolled for the first time. Brazed gas-pipe made of brass was used in New York in 1836. Methods of manufacture improved continually, but it was not until after American copper from Michigan had become available that American brass-makers took the lead over their English rivals, whom they have outdistanced ever since.

Materially the fundamentals of a brass casting shop consist of the furnaces, crucibles, and molds. In the ordinary founding of brass mills of to-day, those that have not yet adopted electric furnace methods, a caster of three hundred years ago might easily recognize the basic equipment if he were brought to this age. A natural draft furnace is used, and our seventeenth century visitor would note the fact that anthracite coal or coke is used as fuel instead of charcoal or wood as in his time. Only one crucible is heated in each modern furnace, while the older practice was to place as many as eight in the same furnace. No doubt the intruder from the past would approve of the chimney that carries off the smoke of the furnace; he would remember his furnaces that belched the smoke unpleasantly into his casting-room. Crucibles now hold from 150 to 300 pounds of metal, and their usual life is from twenty-five to thirty-five heats, depending upon how well they are treated during firing and pouring. These containers of the molten metals, made of clay and graphite, represent an improvement over the crucibles of many years ago because the older ones were not made with the graphite, which greatly increases durability. Instead of the stone of older days, modern molds for brass are gray cast-iron. Sketches of the

old stone molds and those of a modern shop placed side by side would show a remarkable similarity in the way in which they are fastened together and the slant that is given them, but modern brass cast in flat bars or cylindrical billets finds itself put to many more uses than the older metal despite the similarity of their molds.

The head caster of the brass shop of the usual type is boss of process as well as labor. The whole production, from lighting of the coal fires to the cooling of the cast metal, is in his charge. Controlling the fires, charging the crucibles, stirring and skimming the metal, preparing and pouring the molds are under his direction or actually done by him.

About a dozen furnaces are fired at one time under his direction. The crucibles must be warmed carefully before they are charged with metal so that they will dry out without flaking off or cracking. After the charge of copper ingots or copper scrap is placed in the crucibles so that it will melt without harm to them, a handful of common salt is thrown over the partly melted metal and stirred in to prevent oxidization and remove the oxide that has been formed in the metal. When the copper has melted and reached the proper temperature according to the judgment of the caster, the spelter is added. As zinc is lighter than copper it will float on top of the molten metal, but if it is allowed to do this it will take up with oxygen of the air in chemical bondage and thus be lost to the molten brass. To prevent this and to preserve the brass, the caster stirs the zinc into the copper thoroughly and covers the molten metal with a layer of charcoal or

some other material that will act as both flux and a protection from the acquisitive oxygen. Then the caster must be alert and be ready to pour the metal at exactly the right time; the metal must be sufficiently hot, but if it is allowed to heat too much a large amount of the zinc will escape. His sense of touch tells the caster when the melt is ready to cast; the boiling zinc sends a peculiar vibration through his stirring-rod. A block and tackle attached to a light jib-crane is used to lift out of the furnace the crucible seized in a pair of tongs. Then the caster has the disagreeable task of skimming off the dross. To remove these impurities he must stand in a white cloud of escaping zinc oxide that pours off because of the removal of the protecting charcoal. He necessarily breathes some of this zinc compound, and after such continual exposures he often suffers from "spelter shakes," a form of poisoning. As soon as possible after the skimming, molds are poured. This is an operation requiring skill, and there are many chances of producing inferior castings. The making of brass by these methods has never been reduced to a science; the casters go through the school of experience as apprentices and learn the secret and the knack of successful brass making and casting. Often through the use of these inexact methods there are greater variations in the composition of brasses turned out by a casting-shop than the manufacturers are usually willing to admit. A large amount of the variation arises through the volatilization of the zinc.

Oil-fired furnaces, now in use by some foundries, represent a decided improvement over those heated by

coal, since through the use of liquid fuel a better control of heat is possible. Ashes and dirt are eliminated with a consequent refinement of the process. The oil-fired furnaces depart from the arrangement of medieval casting-shops, and the new method of heating allows larger furnace units to be operated. Oil firing also led to the introduction of mechanical handling of the crucible, so that a considerably heavier tonnage of metal can be melted at one time.

Many brass manufacturers now use the electric furnace for melting and alloying copper and its junior partners. The heat that flows along copper wires, cold until it is needed, can be accurately controlled in intensity and distribution; electricity will stir the metal more thoroughly than human energy; and heating by electricity can be accomplished without loss of metal or contamination by burned fuel or the air.

For brass a furnace is used in which the molten metal heats itself because of its resistance to the flow of the current. As it heats itself the metal can also be made to stir itself and distribute the heat if the furnace is constructed to bring about this effect. Electricity can also be made to replace the skill of the experienced boss of the crucible foundry in telling whether the copper is hot enough to stand the addition of the spelter, and whether the brass is of the proper temperature to pour into the molds. Automatic records of the temperature are taken by electric thermocouples whose sensitive parts consist of two wires of different metals joined together inside the furnace. The furnace-chamber is kept entirely closed during the operation, except when the furnace is being charged

or skimmed, and there is little opportunity for impurities to enter. Despite the better conditions of the electric furnace, it is general practice to sprinkle protective charcoal on the top of the molten metal just as was done in the crucible process. Pouring of the molds is accomplished by tilting the electric furnace, whose spout and automatic tilting device discount the skill of the operator.

Brass is perhaps the most difficult of the copper alloys to make on account of the likelihood of the zinc volatilizing. Bronze and the other partnerships that copper helps to form, though easier to concoct, are made in an electrical furnace usually of a type different from that used for brass. A revolving furnace heated by an electric arc that is not in contact with metal is often used for bronze.

Now that you have been told the story of how brass is made, you also know the history of the formation of the other partnerships that copper enters into. All of them pass through about the same experience as brass.

Brass, bronze, and the other alloys are not always destined to become sheets, rods, wires, or tubes but often emerge from the foundry in their final form as castings of machine parts and in other cast shapes. When this is the case, instead of the billets and bars, the final shapes are poured directly from the crucibles or furnaces, using sand-molds similar to those in which copper is cast. But, if bars and billets are made, they are rolled and drawn through the same experiences that their copper prototypes pass through and finally emerge as sheets, rods, wires, or tubes.

Some of the every-day things we see around us wear coats of copper. Sad to say, deception is the motive of some of the baser metals donning red metallic coverings; in other cases a film of copper preserves an artistic or mechanical shape or reproduces it with fidelity, and at times copper is the underclothing of other metals, as it were. Coats of copper are applied by electrolysis. And electroplating is not the first application of electrodeposition that has been useful to copper, if you remember. When the copper passes through the great electrolytic refineries it goes through a similar change from metallic copper to solution, and then back again to metallic copper deposited as a solid. Then, if you remember, when tin cans are thrown in copper sulphate laden mine-water, and their iron is exchanged for the water's copper, essentially the same sort of deposition occurs, although in this case an outside source of electricity is not needed, as the action is self-contained.

Of all the metals, copper is the most easily deposited, and this is fortunate as it is the most useful after it is spread out in a film over another metal or substance. The simplest method of creating a copper coat, perhaps, is to stick your knife-blade into a solution of copper sulphate. It will come out with a reddish film of pure copper. But while this is a simple, easy method it is not the best; the film does not stick and easily rubs off. In practice electroplating is accomplished by placing the objects to be coated in a vat containing a solution of some copper compound. An incoming current passes through plates of copper also immersed in the vat and carries with it some

of the copper into the solution, and then takes copper from the liquid and spreads it over the object to be coated. The solid copper that is being used is attached to what is called the positive pole or the anode, while the object being plated is the negative pole or the cathode. This does not sound complex and it is not, except that in practice close attention must be paid to the rate at which the current flows and the regularity of the deposit. The electrolyte must usually be kept in constant motion so that the deposition is of the same thickness in all places. If all the conditions of deposition are not just right, the metal is likely to deposit in a powdery non-adhering form. If the current is too strong, "burnt" deposits, discolored and useless are produced. Large objects being coated are usually suspended in the tanks by hooks or wires, and they have to be moved constantly to be fully coated; and small articles are often heaped together with the cathode buried among them.

The solution from which the copper is deposited, the electrolyte, may be various salts of copper, the sulphate, chloride, acetate, or cyanide. Electrodeposition on its largest scale, that of copper refining, utilizes the sulphate, as you remember. Copper sulphate is also the common electrolyte used in copper deposition when no other metals are concerned. But the cyanide is used when the plating is done on or in the presence of the other metals. The reason for this is that iron and zinc, two metals that are often plated with copper, are unstable when in contact with copper sulphate or with the sulphuric acid that is always present in the copper sulphate electrolyte. They have a tendency to

give way to the copper just as the tin cans do, and the films formed are non-adherent. Copper cyanide, doubly poisonous though it is, is the only common compound of copper that does not harm these two metals.

In practice a double cyanide of copper and potassium is used as the electrolyte; for the cupric cyanide is insoluble in water, while it will dissolve in a solution of potassium cyanide that is easily made with water. This solution is inferior to the sulphate in conductivity, but its current carrying capacity is usually increased by heating.

There is hardly anything that can not be given a coat of copper, electrically applied. Wood, wax, cloth, rubber, clay, plaster, leaves, flowers can all be preserved by red metal protection. And this can be done despite the fact that such substances do not themselves conduct the necessary electricity. This lack is remedied by giving the poor conductors a black coat of powdered graphite that allows the current to flow. But the creation of novelties or practical objects with a base of such materials is not so important as the deposition of copper on other metals. Sometimes a copper coat is valued for itself alone, but at other times it is a stepping metal to the deposition of some other metal. Copper is a very electronegative metal; this means that it is relatively easy to deposit upon a more positive metal, and the reverse is also true. When it is desired to coat one metal with another that is very close to it in the electromotive series, it is often found economical first to coat the base metal with a film of copper and then deposit upon this red coat the other more positive metal. Nickel-plating is often

done over such copper underclothes. A lone copper film is valued because of its ability to protect more delicate metals from rack and ruin; a coat of copper properly put on substitutes for solid metal very well for a short while, as long as it is intact.

Copper is manufactured electrolytically in some cases, although many more such processes have been worked out in the past than are used to-day. Seamless tubes are made by depositing a thick film of copper on a rotating cylinder that can be withdrawn, and often very large tubes weighing up to five tons, which are difficult to draw, are made in this manner. This is also the first step in a method of making copper sheets; a cylinder of copper is deposited then slit lengthwise and flattened out. One method of producing wire, which cannot, however, compete with rolling and drawing, is to deposit the metal on a cylinder as a strip which is then drawn down to size in the usual way.

A copper film is useful because of its fidelity in duplicating shapes. The little copper molecules snuggle up to the material on which they are electrically placed and so faithfully reproduce it that it is sometimes hard to distinguish between copy and original. Type and engravings made in soft type-metal or zinc, which if actually used would wear away in little time, are given hard surfaces by electrotyping. In some cases, the type or engraving is made dirty with a light coat of grease, and a film of copper is deposited on its surface. This reversed plate is stripped off and used as cathode in its turn, and the result is that the finest lines of the original are accurately reproduced.

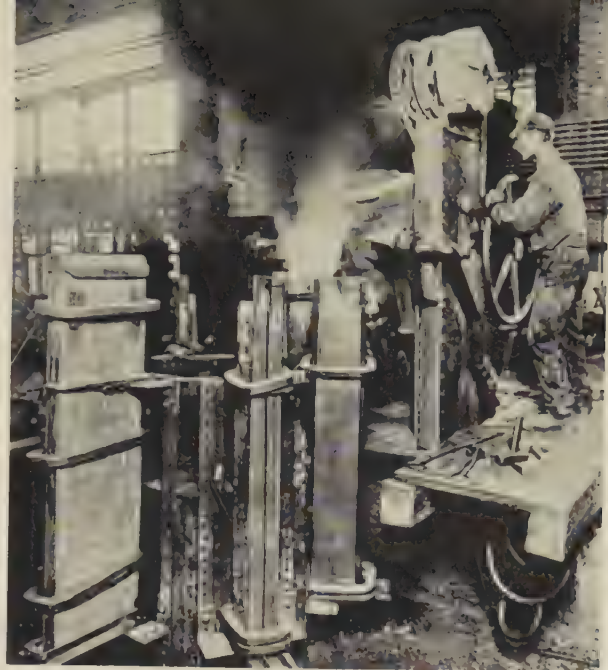
Another, and the usual method, is to make a wax imprint of the plate or type and to use its contact surface, graphitized, to deposit the copper of the new plate upon. By the same methods all sorts of objects of many different materials can be faithfully copied. Medals, statues, other works of art, wood blocks, *objets d'art,* can be counterfeited with the aid of copper coats. Hollow copper objects can be made by molding a core of fusible metal, electroplating it with copper, and then making it so hot for the metal that it runs out and is ready for use again.

Occasions arise when the material to be coated cannot come to the electroplating vat, and the vat must go to it. The barnacles that clutter up and hinder the hulls of ocean-going ships do not like copper and will not attach themselves to it. Sailing-ships of several generations ago were sheathed with copper, and, though modern ships are made of iron, copper barnacle protection is still desirable. Electroplating vats are constructed with the ship's hull as both side and cathode, and in this way hulls are copper-plated. Another method of coating large exterior surfaces is to paint them with a brush constantly wetted with the electrolyte and concealing a wire anode buried among its hairs or bristles.

Coats of brass, bronze, and other alloys of copper can be similarly applied to objects, but each alloy has its idiosyncrasy. Brass cannot be successfully deposited from the sulphate solution for the same reason that copper and zinc can be sucessfully separated from each other during the electrolytic purification of copper. From a sulphate solution the copper is

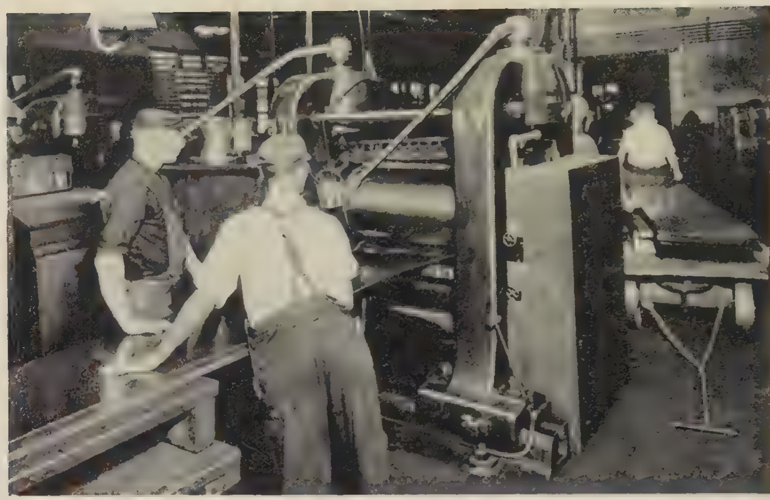
PIT FURNACES IN A MODERN BRASS CASTING SHOP

The men are stirring the metal heated by coal fires.

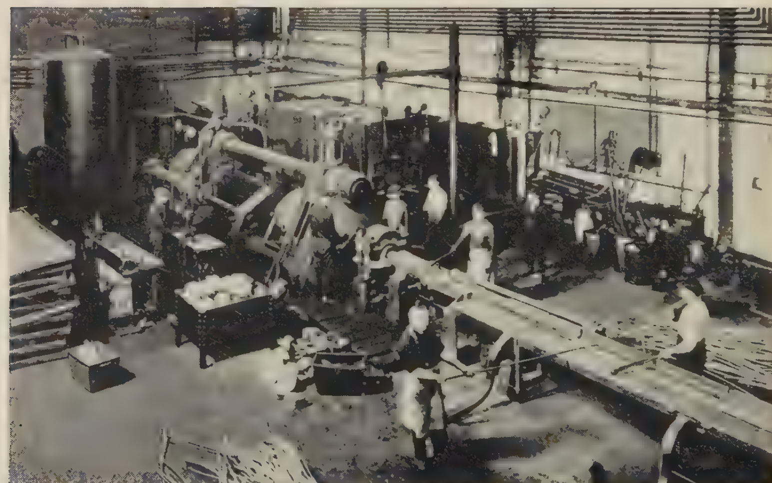


Courtesy of Bridgeport Brass Co.

POURING BRASS FROM ELECTRIC FURNACE INTO MOLDS



ROLLING SHEETS OF COPPER



Courtesy of Bridgeport Brass Co.

THE MACHINE THAT EXTRUDES PLASTIC BRASS LIKE SO MUCH MACARONI

Rods squirted out by this extrusion machine are either drawn to shape and straightened for shipment, or they are drawn into wire.

deposited while the zinc is left in solution. Thus a cyanide solution must be used fundamentally for the same reason that this salt must be used for depositing copper. Even when a copper-zinc-potassium cyanide solution is used, more zinc must be placed in it than is desired in the brass because the zinc is still much more backward about depositing than the copper. Simultaneous electrodeposition of copper and zinc in the form of brass has been suggested as a method of alloying these metals to make brass, and, although it can be done, furnace methods are more economical. For electroplating with bronze, another salt is used, a combination of copper, tin, and ammonium oxalates. German silver, the alloy of nickel, copper, and zinc, is deposited from a cyanide solution.

Though copper does not rust away like iron, it does lose its brilliant red color when it is exposed to the air. There forms a coat of tarnish—or oxide, to use a pleasanter and more correct term. In many cases this skin-deep coat that comes through service, like the sunburn on a sailor, enhances copper's beauty and makes it more desirable from an artistic point of view. This becoming tarnish is often acquired naturally, but as often an even coat is applied artificially. Copper heated to a high temperature takes on a black dull finish. A variety of other effects can be produced on copper by various processes. Time and weather form patina, as the green carbonate of copper is colloquially called; not only can chemicals form the true verdigris, copper acetate, but time can be dispensed with and the effect of age can be produced overnight. Bronze and brass have the same ability

to look artistic when tarnished, because of the copper in their make-up, but the tin alloy wears its film of impurities most artistically. The truth of the matter is that brass appears best when highly polished, and the constant use of energy and polish necessary to keep it shiny is one reason why in these days of high labor costs it is not usually used purely as an ornament. Shiny brass, as well as polished copper, can be preserved without undue work and trouble if a transparent lacquer or varnish is spread over it as a protection to the surface.

Whither go these millions of pounds of copper that are fabricated each year? Earlier in this story, a table giving the approximate distribution of the copper used in each class of fabricated material was given. Estimates of the distribution of the copper consumed in the United States according to its ultimate uses have been made. During 1919, 1920, and 1921 the annual consumption figures were approximately as follows:

	Millions of pounds	Per cent.
Electrical manufactures	295	30.1
Wire and rods not otherwise included	153	15.6
Telephones and telegraphs	85	8.7
Automobiles	82	8.4
Ships	71	7.2
Bearings and bushings	62	6.3
Buildings	60	6.1
Machine fittings	27	2.8
Railways	26	2.6
Ammunition	21	2.1
Coins	3	.3
Fire-extinguishers	2	.2
Pins	2	.2
Cash-registers	1	.1
Miscellaneous	91	9.3
Total	981	100.0
Manufactured for export	127	....

The diversity of the places in which copper does its work compares favorably with any other common commodity upon which the world is dependent. And the way in which copper enters into the heart of our national and personal lives is an interesting story.

CHAPTER X

THE METALLIC SERVANT OF ELECTRICITY

Suppose some fine winter morning the world should awake, yawn and stretch, and then discover that all the electrically-traveled copper in the world had been changed to sealing-wax. It would not take long to make the discovery. What a howl of discontent would be raised to the heavens! No light would beam forth with the punch of a button. There would be no water, hot or cold, for shaving. The electric cars would stand still on the tracks, and even the automobile would refuse to spark its gasolene through sealing-wax wires instead of copper. The telephone would not function. Radio and telegraph would be useless; each small community would be totally isolated from the rest of the world. And a thousand other things would be radically wrong with the world. To be sure, there is little likelihood of such an Alice-in-Wonderland transformation happening. But just suppose. It would be a terrible hardship for our civilization to revert to the conditions of fifty years ago, before the extensive use of electricity began. We need and use electricity's metallic servant, red metal, more than we know. The prehistoric barbarian with the first chunk of copper could not have realized the electrical use of the new material; even Ben Franklin's sagacity failed him and he could not have even a glimpse of the future

power that artificial lightning, copper-carried, has achieved. And probably the most theoretical and imaginative electrical engineer and physicist cannot tell just where the copper-electrical age will end.

Less than a century ago Faraday conducted his brilliant researches into the nature of electricity that laid the foundation of its modern applications. It was an epoch-opening day when Michael Faraday, son of a blacksmith, spun a circular copper plate between the poles of a powerful magnet in the laboratories of the Royal Institution of Great Britain and thus operated the prototype of our immense current-producing dynamos of to-day. But it was not until the eighties of the last century that the great mass of electrical research began to give returns that impressed the commonplace mind. Then the Edison electric light blazed forth, copper-carried current replaced horses as the pulling power for street cars, and men could actually talk over copper. People began to appreciate copper wires and what they could conduct. The production of this metal naturally felt the impulse of a new use, and red metal entered into its second growth. Only at this late date does it seem perfectly natural to think of a small copper wire transmitting power that can be changed into mechanical motion or light or heat at will, just as a pipe carries water.

There are only three practical methods of sending energy from place to place: by mechanical means consisting of a shaft or a belt and pulleys; by compressed liquid or gas, such as water or air forced through pipes; and by electricity flowing through wires. Can you conceive of pulleys, belts, and shafting so

flexible and efficient, and pipes so strong and tight, that they would carry the power equivalent to that carried as a routine matter by every trolley-wire and house feeder? By its aptitude for power-carrying, copper is taking the waterfall to the heart of the city; one instant tons of water drop; the next, tons of machinery hum. The quantities and potentials are much more immense than in the early days when a few volts sufficed. The public was recently thrilled by the news that a million volts of electrical current had been transmitted and made to jump with a great nine-foot silky arc from two copper contacts. On the Pacific Coast 10,000,000 pounds of copper are being used in the construction of the highest voltage transmission-line of the world, conveying current at a potential of 220,000 volts.

As the servant of electricity, copper is surpassed in efficiency by only one metal, silver, which will not hire itself out at a low enough price to compete. Even so, silver is only 6.2 per cent. more efficient than copper. The closest rival of copper is aluminum, which conducts with 60.5 per cent. of copper's ability but has never stayed in real competition for copper's job. Gold, with 71.8 per cent. of the conductivity of copper, cannot, because of its high price and lack of efficiency, compete in electrical matters. The light metal, magnesium, is put out of the electrical conducting contest on two counts, its 35.8 per cent. conductivity and the likelihood that it would act like a flashlight powder on the first mild but heating overload unless the wires were laid in a vacuum. Zinc is low in conductivity, having only 27.2 per cent. of copper's record, but was

used electrically in Germany when war needs caused a severe copper shortage. Since the war and upon the resumption of copper imports, Germany has absolutely ceased using zinc in electrical apparatus; such material is only exported. Iron also is a very poor conductor of electricity and is used only when high conductance is not a necessity or when copper cannot be had.

Only one metal has ever threatened copper's absolute supremacy as the servant of electricity. Aluminum with less than two thirds the conductivity is at the same time very light; it weighs only a little more than one third as much. Thus an aluminum wire weighing only half as much per foot as a copper wire would conduct the same amount of current, although it would be two thirds greater in area. For ordinary wires, the bulk and cost of aluminum have prevented its use, but for high-power transmission it has been looked upon with some favor, and at one time the transmission-lines running into Butte, Montana, the largest copper-mining camp in the world, were of white instead of red metal. They have since been replaced with copper. Data show, however, that copper is mechanically much stronger than aluminum, that for equal cross-section aluminum has but half the strength of copper, and for the same electrical conductivity the breaking-point of aluminum wire is about 80 per cent. of that of copper wire. This means that if copper or aluminum is used on a power transmission-line the aluminum wire would break with 80 per cent. of the strain required to break the copper wire, assuming that neither wire was the least bit scratched

or nicked. As aluminum is very soft, it is more liable to injury, and slight mechanical injuries which may readily happen in erecting or handling an aluminum wire reduce the mechanical strength of the wire greatly. It is possible that sudden breaking of aluminum wires which occurs from time to time is due to such injuries suffered during erection. Aluminum's lack of strength was compensated for by making the large aluminum cables with steel centers to take the load, but in hilly country it has been found that the outside layer of soft metal will not "stay put" and will creep down toward the low end of the line, slipping on the steel center and causing a bunching of loose aluminum wire at low points. Though this drawback is still troublesome it has been overcome to some extent by using double clamps, one for the aluminum and one for the steel. An arc, because of a short circuit or of wires momentarily swinging together, may cause serious damage to an aluminum line on account of the low fusing point of that metal. An arc on an aluminum line usually burns and pits the wire, and as a result reduces the mechanical strength. With a copper conductor, however, the arc has little or no effect, as the resulting heat is carried off and dissipated as easily as the current is conducted.

The fact that aluminum of the same conductivity is considerably lighter than copper, the ratio being two to one, leads some engineers to think that lighter towers could be used. Experience shows that the reverse is the case, because it is not the dead-weight of the line that determines the necessary strength of the tower, but the strains in the towers and cables

because of winds. Aluminum has a cross-section 64 per cent. larger than the equivalent copper wire, and therefore offers more resistance to the wind and hence causes a greater side pull. Under sleet conditions a greater area of sleet will collect on aluminum than on copper, and at such times there are generally high winds. Aluminum, on account of its greater coefficient of expansion and low tensile strength, requires higher towers; experience has shown they must be at least 10 per cent. higher, or, if towers of the same size are used, they must be placed closer together, increasing not only the cost of the towers themselves, but also the cost of digging and installing tower footings and insulators and of stringing the wire. Under certain conditions, because of the greater sag of aluminum wire, wider right of way is required for the wire to sway in. Copper, being heavier and also having a smaller diameter, and being strung with greater tension, will sway less than aluminum when the wind is blowing either at right angles or partly or wholly in the direction of the line. The cost of erection of an aluminum line is likely to be greater than with copper on account of the necessity of greater care and inspection. Aluminum's softness causes its wire strands gradually to wear in two at insulators, and sharp sand or dust in localities having sand and dust storms aggravates this condition. It is also asserted that extensive contact between galvanized steel and the softer metal invites corrosion especially where atmospheric conditions are unfavorable. Thus, while on paper there is sometimes a saving through the use of aluminum conductors for high-tension current, in practice

it is generally found to be uneconomical, because of the much lower factor of safety. Copper is coming into its own again as the most desirable conductor for high-tension lines. Nearly a thousand miles of copper cable, which became the highest-pressure overhead line in the world, were recently shipped to California wound on 1928 reels, each containing half-a-mile of conductor. It was the largest order ever placed for transmission cable, and the shipment required 107 cars. This cable is built like a rope from seven wires of seven strands each, and each of the forty-nine wires is a little more than one tenth of an inch in diameter. The weight per mile of the cable is 8400 pounds, and a new kind of threaded cast connector is being used for the first time on this lot of cable.

Many transmission-lines, a large number operating on 110,000 volts, connect power sources with industries and cities. In the future many more miles, requiring many thousands of pounds of copper per mile, will be required. The electrical expansion of this country is still in its infancy, although it has progressed at a greater rate here than in other parts of the world. Most of the power is now generated at steam or hydro-electric plants that supply one particular region alone; in the future we may expect to see high-tension lines covering the industrial parts of the country like a fish-net. All the available water falling wastefully to the sea will be put to work and transmuted into power to be fed into the general arteries of the red metal muscles of the nation. Steam-plants at the coal mines will economically turn past sunshine into present electrical power and thus use the coal more efficiently than in

these days when it must be transported by steam railroads to its place of use. Instead of ribbons of steel, wires of copper will deliver the energy of the coal mined in the future. You will buy your coal from the power company by the meter-full and have it delivered by wire. On the cloudless deserts where billions of horse-power of solar energy rest unused, power-plants will be established connected to a copper outlet. And, when there is a national power net, we may expect to see the moon as well as the sun harnessed; the slow power of the tides will benefit man. From gas made of peat and lignite, sources not now extensively exploited, power will be obtained to satisfy the increasing craving for energy. In Italy volcanic heat is used to create current for use in cities some distance away, and it is predicted that copper will do its share in tapping the inner energy of the earth for man's use.

Government engineers have already surveyed the first proposed "superpower" system that could effectively net all of the North Atlantic industrial region from Boston to Washington for power purposes. In this zone in 1930, 31,000,000 kilowatt-hours will be required, and the United States Geological Survey reports that this energy could be supplied by a coördinated power system at an annual cost of $230,000,000 less than by an uncoördinated system such as is now in use. There would be a saving of about 50,000,000 tons of coal each year, an amount that posterity would appreciate. The total investment in generating and transmission facilities for the superpower system would be $1,109,564,000, of which $416,346,000 would be the value of existing equipment to be incorporated

in the new system. Of necessity, much copper would be used in making this expansion. The great Colorado River, serving and cutting the Southwestern States, is the power source out of which will arise an industrial West the equal of New England. Once state's-rights are settled and the necessary development begun, many millions of pounds of copper will be required. As it is, an electrical journal estimates that during the next decade in eleven Western States electrical plants will be constructed with a capacity of 2,800,000 horsepower requiring 280,000,000 pounds of copper. Europe and South America have large electrical programs ahead of them, and some day, perhaps not very soon, Asia and Africa will be marked with lines of power.

In addition to the many thousands of pounds in the transmission-cables, much more red metal is used in the generators, transformers, and motors that create, change, or use electricity. From immense generators that send out their product pitched at thousands of volts, the current travels over the copper cables until it nears its point of use. Then thousands of volts are stepped down by large machines to hundreds so that they can be used to feed our lights, run motors, and otherwise energize the world. Wherever electricity must flow in these machines, there copper must be to carry it along.

One of the most promising applications of copper and electricity is to railroad transportation. If we had our railroads to rebuild, a steam locomotive would be a rarity. The possibilities of railroad electrification can be visualized from the following quotation

from the superpower survey report: "Within the superpower zone there are 36,000 miles of railroad measured as single track—that is, including each track of main lines, yards, and sidings. Of this total about 19,000 miles can be profitably electrified, so as to yield by 1930 an annual saving of $81,000,000 as compared with the cost of operation by steam. The capital expenditure necessary to electrify the 19,000 miles would be $570,000,000, and the average return upon the investment would therefore be 14.2 per cent."

Electric trains have many advantages over those hauled by steam. They can get under way much faster, achieving the speed of thirty to forty miles an hour in about as many seconds. They are speedier; an electric locomotive holds the world's record for railroad speed, 131 miles an hour. Trains can be run at closer intervals if the road is electrified, and the dirt and cinders of steam travel are absent. The engineers laying out an electric road can include grades that steam locomotives could not climb, as an electrical locomotive can call upon the energy of immense machines in distant power-houses to help it climb hills. Paralleling the two steel rails of the ordinary railroad, the electrified line has an elevated wire of copper carrying the electrical energy so that it can be tapped at any point. A considerable mileage of railroad track has been converted to copper and electricity here in America and in Europe. The American heavy-traction roads that have either changed over or begun to do so include portions of the New York Central; New York, New Haven, and Hartford; Norfolk and Western; West Jersey and Seashore; Pennsylvania; Chicago,

Milwaukee, and St. Paul; and Butte, Anaconda, and Pacific railroads. For each mile of electrified road from 8000 to 35,000 pounds of copper are used. In the superpower survey it was estimated that 13,500 pounds of copper would be needed for contact wires alone on a double-track system.

The street railways are also large consumers of copper in wires and equipment. The ordinary city electric car contains from 1000 to 2500 pounds of copper, and some of the larger interurban cars have nearly 4000 pounds. A ten-car subway train in New York contains about 30,000 pounds of copper. Including the feeder system, overhead trolley, bonding, car equipment, and power-house contents of copper, the average city electric line uses from 15,000 to 20,000 pounds of copper to the mile of track. As there are approximately 45,000 miles of electric railways in this country, about 675,000,000 pounds of copper are used in the street railway business. The other modern forms of transportation are just as subservient to copper and electricity as electric traction. No automobile or aëroplane could run without its ignition system, any more than an electric automobile could travel without its storage battery.

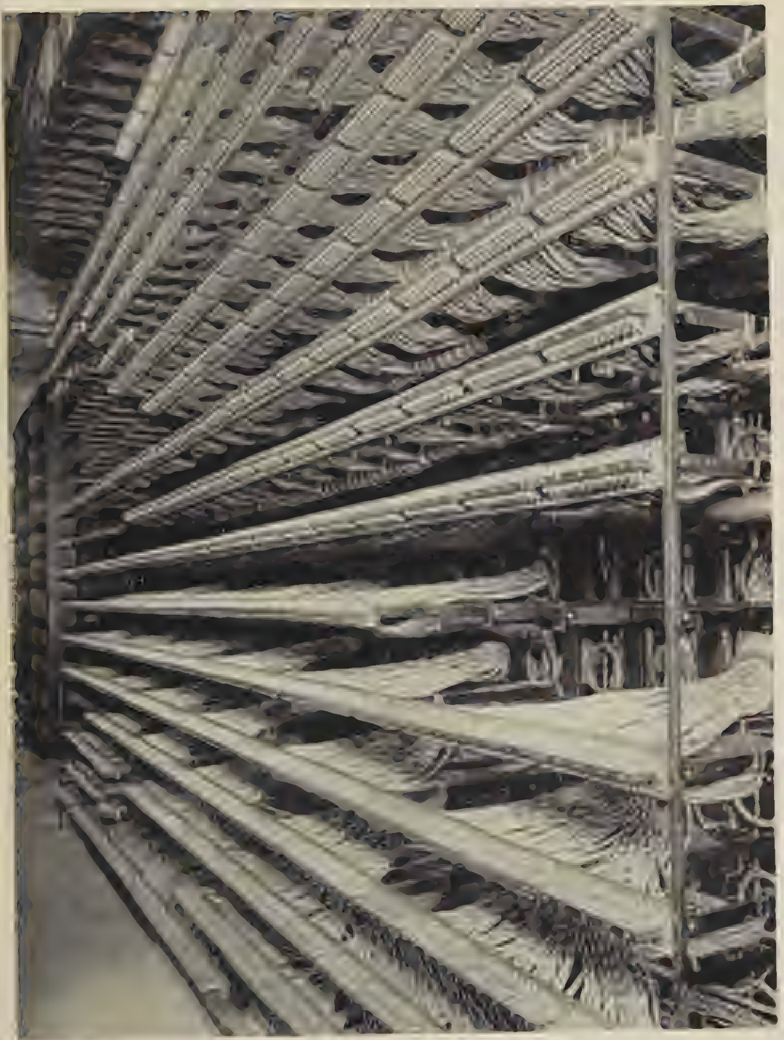
More than half of the copper mined, smelted, refined, and manufactured in this country is used in the electrical industry. Industrial power is the field of greatest promise for the future of the combination of electricity carried by copper, but whatever electricity touches must have copper. Even the electric fixtures and fuses which do not actually carry current need copper as a component of their brass. Incandescent

lamps to the number of about 150,000,000 are manufactured each year, requiring 1,000,000 pounds of copper. We think of using electricity as a source of light primarily, but current would much rather turn itself into heat than light. In fact it does, as you can prove for yourself by putting your hand on an electric lamp. Current is an ideal heat-producer without flames, smoke or ashes, and the future will see our furnaces made of resistance wire set conveniently in every room of the house. Copper-carried current is a very useful thing to have around the house. It will percolate the coffee, make tea in the samovar, warm the milk for baby day or night, cook cereal or milk, toast bread, fry eggs, cook food in a chafing-dish, pop corn, bake griddle-cakes and waffles, knead and bake bread, heat the flat-iron, the fireless cooker, or the electric range, warm water for shaving or the bath, sterilize water or utensils, curl and dry hair, light cigars, keep heating-pads hot to replace leaky hot-water bottles, heat the bath-room on a cold morning, thaw frozen brass water-pipes, wash dishes, polish the silver, operate the washing-machine and clothes-wringer, dry the wash and iron it, run the vacuum-cleaner, polish the floors, operate the sewing-machine, play the piano, massage the face, cool you with an electric fan, make ice, mix family beverages, illuminate the house, protect the house from burglars, run the dumb-waiter, give electric treatment and electric baths, purify drinking-water, amuse the children with electric toys, and haul the family in an electric automobile.

The nerves of the world are copper. More important than the red metal arteries that bring power are

the metallic wires that carry thought. The world has had its nerves, the telephone and the telegraph, much less than a century, but now it could not part with them and still live as it does. Radio is a recent addition to the world's nervous system, which has virtually annihilated the fourth dimension, time.

By far the largest investment in a single raw material is the $100,000,000 that the Bell Telephone System has tied up in the approximately 700,000,000 pounds of copper estimated as contained in its nation-wide system. In the other telephone plants and systems of this country, according to mileage figures, there seem to be in the neighborhood of 100,000,000 pounds more. In the telegraph lines of the Western Union and Postal Telegraph companies, there is probably an additional 200,000,000 pounds of copper, and the miscellaneous independent telephone and telegraph lines operated by railroads and private companies are estimated to contain about 50,000,000 pounds of copper. In all the telephone and telegraph plants of this country there are therefore about 1,050,000,000 pounds of copper. It is said that the United States contains 60 per cent. of the total telephone and telegraph mileage of the world, and if this is correct the total amount of copper used in the world's telephone and telegraph systems is about 1,750,000,000 pounds. In the Bell system there are nearly 28,000,000 miles of copper wire, and there are about 34,000,000 miles in all the telephone systems of this country. Only a small portion of this is strung up on poles, single stranded, as telephone and telegraph wire is actually visualized. Eighty-six per cent. of the miles of Bell system nerves are in underground



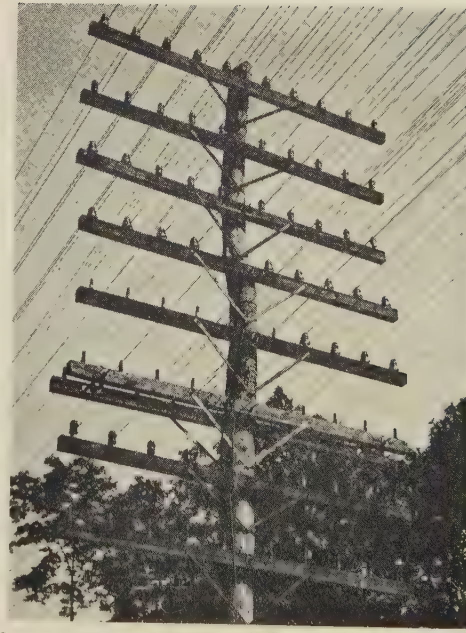
Courtesy of American Telephone and Telegraph Co.

COPPER NERVES

The thousands of copper wires through which flow the electrical current carrying the voices of the city. View of the back of a telephone central station.

2400 COPPER WIRES

A piece of telephone cable only 2½ inches in diameter, especially prepared to show its construction. Each of these 1200 pairs of copper wires has its own place and knows it in spite of close quarters.



Courtesy of American Telephone and Telegraph Co.

OVERHEAD COPPER WIRES

Individual telephone wires strung on poles. This is a common sight, but most telephone wires are placed in cables, especially in cities.

and aërial cables, sometimes as many as 1200 pairs of wires running along together under the same protection. If all the copper wire that is used to-day were strung on the surface of the ground there would be little room for anything else in parts of our cities. Would you like to have the sensation of using 2,900,000 pounds of copper? Go to New York and call up San Francisco on long distance. You will be telephoning over a transcontinental line of 3400 miles.

As a new part of our daily life we have acquired radio. Compared with the voice-transmitting wire telephone and the correspondence-transmitting wire telegraph, the radio that talks and stutters broadcast through the ether is called wireless. "Wireless" applied to a radio set is as much out of place as "horseless carriage," the name given to the first automobile. Copper wire is a necessity in the radio set just as it is in any other piece of electrical apparatus. There must be the antennæ on the roof or in a coil to catch the ether vibrations, a lead-in wire of copper must bring them to the set, and then the coils and other parts of the apparatus must transform the radio-frequency current into one that will produce sound in the telephone receivers. The continuous circuit from roof to ears must of course be essentially copper, and, in addition to this, brass contacts and trimmings are often used. In many cases the detector that translates the radio waves into electric vibrations audible in the receivers is a selected crystal of chalcopyrite, the important copper ore. Contrary to the first thoughtless conclusion, radio will not cause a decrease in the consumption of copper for the nerves of the world. Re-

cent advances in telephone science have resulted in a dozen telephone calls and about half as many telegraph messages being sent over the same long-distance wire at the same time, and yet more copper is being used in building new telephone and telegraph facilities. The radio receiver fed by great government transmitting-stations may soon rival the telephone in the rural districts, which are now two fifths equipped with telephone service. Radio enters a new field; it will enable one man to address the world. It is to the telephone what the newspaper is to the letter. We may predict that a time will come when we shall be able to *see* by radio or wire. With these possibilities, the use of radio is predestined to exceed greatly the rosiest dreams of the radio apparatus makers created by the broadcasting boom. With 1,000,000 to 2,000,000 radio sets in use, with each set using only five pounds of copper, this new addition to our national nerves is using from 5,000,000 to 10,000,000 pounds of copper. If this number is increased at the rate of only a million sets a year, a new and important use for copper has been developed.

On a summer afternoon, when nature turns the sky into a leaking power-house and the thunder rolls, a copper lightning-rod is a handy thing to have on top of the house. Yet much has been learned since Franklin invented the single lightning-rod with a sharp point on it. It once was believed that lightning-rods afforded protection by dissipating the charge induced on a building by a cloud, but this idea has been shown to be erroneous. The electrical charges are so great and the connection of the lightning-rod with the ground is such

that the small dissipation of electricity possible through the sharp points of the rods can have no appreciable effect on the total charge. For this reason lightning-rods do not need to have sharp points, and for the same reason the rods cannot attract lightning. Nature hurls her electrical bolts hit or miss wherever she desires. They may strike a building or they may not, but the lightning-rod has little to do with it, say the meteorologists. The important thing is to have something there that will carry off the electricity from the clouds if it should select your house. Then any kind of lightning-rod, even one loose-jointed or badly grounded, will be better than none, for it will provide an easier path to the ground than one through the building itself. Copper with its high conductivity is the best material for rods.

South of the White House in Washington, the Washington Monument rises high in the heavens, the easy mark for every passing thunder-storm. In 1885, when the monument was completed, an extensive lightning protection system was installed, made principally of copper. To-day it stands just as it was installed. Two hundred copper points, gold-plated and tipped with platinum, set on copper rods running along the base and edges of the pyramidion that caps the monument, act as a cage, the best type of lightning protection. Larger copper rods lead to four iron columns that form part of the framework of the interior of the monument, and copper rods convey the lightning to the ground from the column ends.

It is not necessary to gold-plate and platinum-tip your copper lightning-rods. In fact, the best sort of

protection against lightning as well as against the rain that accompanies it would be a copper roof, with copper down-sprouts, well grounded. In storm or fair weather, copper will prove itself a good conductor.

CHAPTER XI

BUILT OF COPPER

As long as copper was in demand for weapons and was not plentiful, ancient man could hardly have used this metal for building material, despite his undoubted recognition of its superior properties. When iron and steel momentarily relieved copper of the burden of fighting wars, when methods of claiming copper from the earth had become improved, when the statues of bronze and copper and the copper household utensils had demonstrated copper's usefulness, beauty, and durability, then the red metal began to be used in the construction of shelter.

In early days copper was too sacred, too beautiful, and too hard to win from the earth to allow its use in the houses of the ordinary people. Cathedrals, temples, and public buildings were protected and ornamented through the use of copper. For example, achæologists have discovered that the Grecian treasury of Atreus at Mycenæ was lined with bronze plates. A thousand years and more later, when St. Mark's Cathedral in Venice was rebuilt and beautified, it was roofed with thin sheets of copper. In many of the other cathedrals of Europe, copper or bronze was also used for massive doors and other parts of the edifice. On the other side of the world there will be found to-day, housing priests of different religions, temples

capped with copper. For five centuries and more these same roofs, which promise long service still, have withstood the storms and the sunshine that their gods have bestowed upon them. China's famous Temple of Heaven in Peking, as well as numerous Japanese temples, are roofed with copper, and at Kanakura in Japan there is a shrine built in the form of a colossal bronze Buddha thirty-six feet high, with eyes of gold. For 670 years this figure, said to be Japan's greatest work of art, has breasted without injury tidal waves that swept away the great temples that sheltered it. It has only weathered to the permanently beautiful green patina.

The industrial and economic advancement that has made the lot of the ordinary worker of to-day easier and better has brought copper within reach of the builder of a modest home. As in the early days, copper continues to be used in sacred and public structures, but they do not now monopolize this material. In our Eastern cities that have had the opportunity of acquiring a past, there are many buildings, far too numerous to enumerate, on which copper roofing has been used for at least seventy years. Some of the most famous structures in America's history have been protected by copper. When Faneuil Hall in Boston was recently repaired copper roofing ninety-five years old was found to be ready for at least twenty-five years' more service. Signers of the Declaration of Independence worshiped in Old Christ Church in Philadelphia, which has worn a copper roof for 173 years, and this same roof, which was already three decades old when our country was born, promises further

satisfactory service. Trinity Church in New York, though now overtowered by copper-capped sky-scrapers, has a copper roof that was laid in 1846, and recently, when a new Fifth Avenue Baptist Church was being built, copper was the roofing material. In Wall Street a modern temple of finance is being built, the new building of the New York Exchange, and copper is playing an important part. The highest point in New York's forest of sky-scrapers is the huge copper-covered lantern on the peak of the Woolworth Building, and low down among these great buildings is the cupola of New York's City Hall, copper covered. Next to the National Capitol in Washington with the bronze Liberty on its dome stands one of America's most beautiful buildings, the Library of Congress. Most striking is its gold dome, "22 carat fine," as the guide-book will tell you; and contrasting pleasantly with this splendor is its roofing of verdigris copper. If the guide-book is closely studied it will be found that the flaming torch of Science and the golden dome are basically black copper supporting a heavy layer of very fine real gold gilt. Such are a few of the famous roofs of America. To list more would be as futile as to include a directory of copper-roofed American homes built for the future as well as the present.

Useful and ornamental as copper roofs are, they do not monopolize the structural use of copper. Even in the buildings that are not graced by a copper cap of pleasing green or brown, large quantities of copper and its alloys are often used in wires, pipes, flashings, cornices, screens, all forms of hardware, and many other building parts. The ordinary person who sel-

dom stops to think about or observe the buildings he inhabits daily does not often realize the extent to which copper and its alloys are used.

Grand Central Terminal in New York is a large community in itself, with stores and offices as well as all the equipment necessary to a large railroad station. Perhaps a mere listing of amounts of copper used for various purposes will prove illuminating.

QUANTITY OF COPPER USED IN THE GRAND CENTRAL TERMINAL, NEW YORK CITY

A Buildings. Includes main station building, Grand Central Terminal Building, post-office and office-building, service plant, Sub-stations Nos. 1 and 1-A:

	Pounds
Roofs, flashings, etc.	361,100
Extended metal	200,200
Kalamine	33,880
Hardware	74,140
Art bronze	139,260
Grille work	4,790
Wiring and panel-boards	126,490
Lighting fixtures	68,980
Switch-boards	6,100
Telephone equipment	5,900
Self-winding clock equipment	3,580
Desk-fans	1,000
Hydraulic elevators	3,260
Electric elevators	26,000
Elevator door machinery	960
Elevator signals	3,000
Baggage-room door machinery	170
Window operating machinery	200
Ventilation rangers	2,630
Motors	19,930
Pump impellers	200
Plumbing fixtures	3,970
Valves	10,850
Tubular water-heaters	1,000
Meters, including brass piping	2,130
Recording thermometers	330
Fire-hose accessories	2,410
Fire-extinguishers	3,800
Refrigerator equipment	290
Laundry equipment	500
Ducts and sheet-metal	2,250

	Pounds
Pneumatic tubes	10,900
Brass railing	6,040
Train indicators	620
Bulletin boards	360
Lunch-counter and boot-black fixtures	3,170
Kitchen equipment	7,000
Soda-fountains	1,800
Receptacles, cuspidors, etc.	1,040
U. S. mail boxes	380
Cash-registers and show-case fixtures	1,390
Store-room stock	2,000
Total	1,144,000
B Service-Plant:	
Conveyors, hoists, and crane	380
Machine-shop and store-room	1,000
Boilers	6,400
Feed piping	3,400
Water-heaters	51,000
Regulators, gages, and thermometers	280
Pumps and motors	13,070
Expansion joints, traps, and valves	5,690
Venturi meters and pressure-tubes	850
Engines	90
Air-compressors	600
Turbo-generators	12,000
Cables	11,950
Switch-board	1,160
Sheet-metal ducts, etc.	1,030
Total	108,900
C Sub-stations Nos. 1 and 1-A equipment:	
Rotaries	64,000
Booster-sets	12,000
Motors	1,300
Transformers	73,400
Circuit-breakers	13,200
Switch-boards	29,500
Busses	217,700
Cables	45,500
Total	456,600
D Yard:	
Lighting and cables	396,200
Flashings, gutters, etc.	78,650
Kalamine	4,050
Traps and valves	10,650
Sewage-ejectors	540
Plumbing-fixtures	480

	Pounds
Trap-screws and floor-drains	3,200
Hydrants and hose-couplings	2,190
Battery charging sets	200
Elevator baggage-trucks	1,480
Mail conveyor equipment and signals	5,300
Pumps	780
Meters	250
Scales	240
Floor-plates	90
Oil-room equipment	500
Total	504,800
E Electrification, Signals, and Interlocking:	
Feeders	22,100
Bonds	33,400
Jumpers	58,900
Cables	118,000
Interlocking machines	50,000
Switch machines	40,500
Switch-machine circuits	148,500
Control cable	1,600
Telephone cable	1,500
Fire-alarm system	1,700
Total	476,200
F Construction Department	
Temporary lighting	12,500
Valves, plumbing, etc.	1,150
Electric driven air-compressors	7,000
Transformers	4,300
Pumps and motors	2,550
Total	27,500
Summary:	
A Buildings	1,144,000
B Service-plant	108,900
C Sub-stations Nos. 1 and 1-A equipment	456,600
D Yard	504,800
E Electrification, signals and interlocking	476,200
F Construction department	27,500
Grand total	2,718,000

The reader has hardly read all of the list, but the mere fact that half a ton of copper is used in the desk-fans in the Grand Central Terminal is impressive.

From the examples that have been given it may be seen that the owners, designers, and builders of the larger structures have realized the economy of building well with permanent material. The average home-maker who buys a ready-made house built for profit and not for permanence is likely to be enticed by temporary veneer, especially as the first cost of the less permanent house is lower. Because America is a land with roofs that must be painted, plumbing that rusts out, screens that crumble, because it is a country that must be continually rebuilt, it is estimated that $626,500,000 is wasted annually. Experts claim that copper and brass can save this loss occasioned by the repairs and replacements made each year on the approximately twenty-one million residences in this country.

The largest single factor in this great extravagance of America is the use of sheet-metal work that rusts out in about five years. The footage of gutters and leaders or downspouting in use would encircle the globe about forty times; or, if you would rather think of it in figures, there are 5,175,000,000 feet of leaders and gutters not made of copper. In money, the loss caused by the use of iron and other inferior metals rather than copper for leaders, gutters, flashings, and valleys in residence construction amounts to more than five hundred million dollars annually. In making the survey, it was estimated that the cost of replacing a rusted, useless piece of sheet-metal would be one and a quarter times the original cost because of the necessity of removing the unserviceable downspout, gutter, or flashing before repairs could be made. In arriving at

these figures for waste in building, it was learned through a careful survey that the average residence has 150 feet of gutters, one hundred feet of leaders, fifty feet of valleys, and 150 feet of flashings, and these were the quantities used in the estimates. Even the immense sum of five hundred million dollars does not include the wall-paper, plaster, and furniture damaged by an unexpected leak, which occurs every so often when rusting metal-work is used, nor does it allow for the damage done to the building in repairing the metal-work. The time and money lost and the trouble caused is a needless overhead similar to the repairs and replacements.

The water that is brought into the home through the plumbing is just as active an antagonist to iron as the rain that flows down the gutters and leaders. When the water is heated it becomes even more eager to release its oxygen to unite with iron, and the result is that in a house with plumbing of iron the pipes will often run water red with rust, or hardly allow it to run at all. Eighty-six million five hundred thousand dollars is the annual fine that is assessed upon those who have iron pipes in their hot-water lines alone, according to the survey made to determine the saving that could be effected through the use of brass instead of iron. If the combination of copper and its junior partner, zinc, were used for the hot-water pipes, this expensive waste could be eliminated.

Man is continually waging war on his most insidious foes, the lower forms of life. Armies of insects cause him trouble, particularly in summer. The aërial branches of those great omni-present hordes are best

combated by erecting a protective barrier. If the War Department were in charge of protecting the nation against this enemy, it would go to Congress for an annual appropriation of thirty-two million dollars. That is the amount spent each year painting, patching, and replacing screens to keep flies, mosquitoes, and other insects out of our houses. If screening were a part of the national defense program, a committee of producers of copper and bronze insect screens would probably go to the general staff and urge them to subsitute their non-rusting products for the materials that quickly rust to uselessness, no matter how much is spent on painting, dipping, and galvanizing them. Because of the lack of a central authority to purchase all screening, the builders and housewives are being shown the advantages of copper or bronze screens that will last as long as the house.

Wastes in ordinary, built-in-a-hurry-for-to-day, American residence construction do not end with inferior sheet-metal work, iron plumbing, and rusting screens, nor with the damage that they incidentally do.

Before the World War, brass and bronze were the accepted standard materials for locks, hinges, and the other common building hardware. But when war came, the copper and its principal alloys that were about to go into their regular peace-time service were drafted and turned into millions of rounds of ammunition. As there was not enough copper to fight the war and stay at home, too, substitutes came into the places that copper left behind. These substitutes, sad to say, were inferior. They would not stay on the job year after year. Their iron was always endeavoring

to run off with oxygen in a streak of rust. The manufacturers realized that this was the case, and in many cases they kept enough copper at home to furnish a temporary guard on the outside of the substitute iron, but this veneer of brass over the iron, though successful in keeping a bright front until it was bought and placed on the job, could not withstand the uneasiness of the iron below. At the first scratch iron ran off with oxygen, regardless of the stain it created. Such conditions had to be put up with when the war was in progress. When the war was over the substitutes for copper, brass, and bronze held on to their war jobs. Copper and his partners came home from war and found themselves without work; they were in the same condition as many of the soldiers with whom they had fought. Although during the war the substitutes were able to demand and get full copper wages on the strength of their brass veneer and the fact that they were badly needed, when the war was over and true copper products were again ready for peace-time work the substitutes found that they could work for less. And the builders, accustomed by this time to inferior work, kept the substitutes on the job and decided to let the purchasers of homes pay the loss at some later date. It takes a little time for inferior work and products to expose themselves, and the path of least resistance is to continue to do things as they are being done. Now copper, brass, and bronze are ready for work at prices lower than before the war, and by showing in cold figures the economy of their service, they are winning back their rightful places in locks, door-knobs,

and all the other kinds of hardware that should serve without trouble and expense as long as the house.

People have the idea that copper is expensive. Perhaps their constant contact with pennies makes them hesitate to cover their roofs with the same material that is used in these coins. Whatever the reason, many look upon copper and its products as a luxury. They have never computed the actual saving in expense that copper's long life allows. But even if they do not wish to look forward and build for the future as well as the present, the added cost of using copper and its alloys is not prohibitively great. If you spend \$1.01¼ instead of \$1.00 you can avoid perpetual leaks and renewals by using copper in leaders, gutters, flashings, valleys, and other sheet-metal work. For less than one cent added to the building dollar, brass hot-water piping can be installed instead of iron. Real copper, brass, and bronze hardware can be installed adding less than 1¼ cents to the dollar, and for 2¾ cents added to every dollar a house may secure the continuous protection of a copper roof.

There is a scene in the future that the builder seldom visualizes. When the building that is being erected to-day is superseded by another, when its usefulness is over, it must be torn down and the materials that have served together so long must be separated. Some bricks are sorted over and used again. But most of the building finds its way to the dump. Iron roofs that have been nursed along with numerous coats of paint then reach the end of their lives and are buried without regret in the rubbish of the dumping-ground.

Iron hardware, too, is seldom worth removing from the second-hand material. Iron pipe has only a very low value as scrap. But with copper or brass portions of the buildings, it is another story. The watchman on the job keeps a close watch over the copper-containing hardware and the brass pipe that is removed from the building, as the junkman pays money for old brass and copper. Often locks, hinges, and other pieces of hardware find themselves again in service in new buildings, while those that have gone out of style with the passing years are sold and their red metal is turned again into the channels of commerce. A copper roof after years of service may find itself laid on the top of a new building, and if it can not continue thus to defy the weather an old metal dealer will pay for the privilege of rejuvenating it and transforming it into another copper product. Because of copper's salvage value, the person who buys a copper roof can consider that he is placing money on deposit as well as saving the cost of construction with inferior metals. The purchase of diamonds is often considered a good way of investing money. A copper roof lends beauty to the house just as a diamond sets off a hand, and a copper roof is nearly as good a bank as the diamond.

Durability, the same quality that results in high salvage value, is the cause of economy in the use of brass and copper in building. This quality of copper products is demonstrated not only by the unsystematized general observation of their lasting qualities but also by some planned investigations that have been made. A large manufacturer of wrought-iron pipe made a survey some time ago of the condition of hot-

water plumbing in 128 Pittsburgh apartment-houses containing 996 apartments. The data justified his trouble and showed that wrought-iron pipe is better than steel pipe for plumbing, but it also proved so conclusively the superiority of brass over both kinds of iron pipes that the brass and copper companies have used these same figures as the basis of an advertisement of their own. Although all the steel pipe had failed at the end of eleven years' service, and all but one installation of wrought-iron pipe was worthless at the end of eighteen years, there was not a single brass pipe failure on record. The steel pipe began to fail at four years, and the wrought-iron after eight years.

The labor cost of laying copper roofs has in the past been a hindrance to their use. Relatively large sheets were used, and they had to be laid by methods similar to so-called "tin" roofs. This necessitated making joints in places, and as copper is a little more difficult to work than tinned iron it took more labor to make the standing seams or other joints. Copper shingles that can be laid more cheaply have recently been placed on the market to reduce the high cost of applying this material. Instead of large sheets, the roofing material consists of rectangles of copper, six or eight inches by eighteen inches, crimped so as to form a joint without any work at the installation. They are claimed to be lighter than any other substantial roofing material; they weigh only eighty-four pounds to the hundred square feet, compared with two hundred pounds for wooden shingles, four to six hundred pounds for asbestos, 750 to 1200 pounds for slate, and one to two thousand pounds for tile of the same area. Copper

shingles cost less than tile or slate, and only twice as much as wooden shingles. For those who do not care for the reddish shade of new copper or the green produced by a few years' weathering, these shingles come in seven different shades, four greens, a blue, a red, and a brown. Nature acts as the decorator of a copper roof. After she has tired of the copper red of a new roof, she often turns it to a rich green that blends with foliage, although occasionally she will form the black oxide rather than the green carbonate. "Patina" is the name of the green coloration; geologically speaking, it is malachite, copper's carbonate, exactly the same as the ore. If the house owner is impatient and desires to have a green roof without the necessity of several years' delay, the roofer can provide it in twenty-four hours by using a simple process. This is the formula:

After the copper-work is completed, make a solution of one pound of sal ammoniac to five gallons of water; let it stand for one day and then apply it to the copper-work with a brush. This application is allowed to remain one day, after which just enough clear water should be sprayed to moisten the copper. The same results may also be obtained by using a solution of half a pound of salt to two gallons of vinegar.

Even though a house is not protected and decorated by a copper roof, copper is often used in cornices and copings, sheathing around windows, flashings in connection with some other roofing material, and weather-strips. When less permanent materials are used virtually throughout, it will usually be found that the highest point in the structure is a copper lightning-

rod. In the case of store buildings of the better class, the whole front of the structure, show-window frame and all, is frequently made of sheet copper, brass or bronze, decorated in relief or repoussé. Brass and bronze façades are a much more common sight in Berlin or Vienna than in this country, in which most of the metal was produced. Bronze doors for banks, apartment-houses, and other buildings, which have become a permanent feature of German building construction, are an outgrowth of the medieval use of bronze doors for churches and cathedrals, and even the motion-picture theaters, hotels, cafés, and restaurants have entrances or fronts of brass and bronze.

Man is not alone in enjoying the advantages that the use of copper gives to buildings. In one of the larger magazines an advertisement may be found that describes a house for wrens, "made of solid oak, cypress shingles, *copper* coping, with four compartments." It declares that "a regard for little details determines whether birds will occupy a house."

In most building construction, from the point of view of bulk and proportion of cost, copper and its alloys play a comparatively small part. But several structures erected in the busiest part of New York City are constructed almost entirely of bronze. These are the new traffic towers along Fifth Avenue from which the flow of more than 15,000 vehicles and 130,000 pedestrians each day is directed.

Many other classes of construction are bettered by a liberal use of copper and its products. In fact, whenever a structure of permanent nature is erected, it is usually advantageous or necessary to use copper in

some form. This metal will be found in greenhouses, burial-vaults, and bridges. Engineers estimate that the use of bronze for a protective covering over the cables and all other steel-work of the $100,000,000 Hudson River bridge to connect Manhattan and New Jersey will save four hundred thousand dollars annually in upkeep alone.

CHAPTER XII

COPPER IN THE HOME

Now that we have learned about copper's birth, training, and career, let us go into the house and see how often we meet it in our every-day domestic life.

As we walk along, observing with a glance at the bronze-lettered lamp-post that we are on the right street, the verdigris green roof of the house stands out in the distance. Copper numerals fastened on a bronze plate or bronze-painted figures on glass tell us the number of the house, and we are helped up the steps by a railing of copper. Next door a brass name-plate announces that a physician is our neighbor. There is a polished brass knocker on the front door, but with some hesitation we decide that it is more likely to be ornamental than useful, and we announce our presence by pressing the brass button, set in a copper frame. Electrical impulses shoot through a copper wire to a bronze bell inside the house. As we wait for the copper-colored maid to answer our ring we admire the copper leaders from the roof and observe that the hardware on the windows and the shutters is made of brass. Copper or bronze screens that have evidently served successfully for many years ornament as well as protect the windows that may be raised. By turning a brass knob which controls a brass lock

the maid opens the door on silent brass hinges, and we are received in the house.

If our minds are tuned to copper just as the radio receiving set we see in the parlor is tuned to a certain wave-length, we are likely to be astonished at the large number of objects in the house that will respond to such a test. We will adjust our eyes and minds so that they are selective to "a band of wave-lengths," as the radio enthusiast would put it; we shall be on the watch for brass, bronze, and other objects, disguised or frankly copper-containing, as well as pure copper.

Everything electrical about the house not only receives its energy through copper but is also dependent upon the use of copper in its operation. Snapping on an electric light-switch allows the current to flow along copper wires into lamps supported by brass fixtures. If we step to the telephone the lifting of the receiver allows a copper-carried electrical current to notify the operator that we want a number. Although "wireless," the radio receiving apparatus snatches its music and entertainment out of the ether by means of wires, and copper conveys the impulses to the 'phones. Alongside the antennæ of copper wire strung up on the roof, a copper lightning-rod can be seen pointing into the heavens.

Rods over the windows that hold the lace curtains are brass, as are those over the doorway from which hang the draperies woven with a woof of bronze. Above the brass andirons in the open fireplace a pair of brass candlesticks are artistically placed, and in one corner on a pedestal stands a bronze bust. A

jardinière of hammered copper on the other side of the room holds a fern.

In the dining-room we know copper is hidden under a coating of silver in the Sheffield silverware on the table. The electrically heated coffee-urn and toaster, like the other electrical equipment of the house, are largely made of copper. A bronze dinner-bell is patiently waiting until dinner. In a golden brass cage hung in the sun there is a canary who plainly asks us to inspect the new house he has been given. If it happens that the house belongs to a family who can trace their kitchen utensils as well as their ancestry back for several generations, we shall find that many of the pots and pans are copper, lined on the interior with a heavy coat of tin, or coated entirely with a film of electrically deposited nickel. Even if the kitchen-ware is made of other materials, you may find that the sinks and drain-boards are coated with copper sheathing and that the hood over the stove is also made of this metal. If we examine the voice tubing through which the lady of the house talks to the kitchen-maid, we are likely to find that, too, is either copper or brass. Throughout the room, in wire brushes, in hardware on the ice-box, and in numerous other instances the red metal or its compounds are being used.

In the laundry there are other examples of copper serving the home. Most of the important parts of the electric washing-machine are made of this non-corroding metal, and no material is quite so satisfactory as copper for the bottoms of wash-boilers. Within the casing of the constant hot-water heater there is a copper coil which suggests the reason why, if a rumor

may be credited, many more of these coils have been purchased during the last few years than have been installed in hot-water plumbing-systems. This is a well-built house that we are in, and naturally all hot and cold water-pipes are made of brass. Our host is proud of the fact that a plumber has not been needed since the house was built. In keeping with the pipes, the spigots and other equipment in both laundry and kitchen are shiny brass. The alarm-clock that ticks loudly on the shelf and tells when to get dinner ready is run by mechanism of brass, and hung in a rack conveniently is a shiny brass-sheathed fire-extinguisher ready for an emergency.

As we go to the second floor, our copper-selective eyes pick out the brass-headed tacks that keep the stair carpet in place, and the golden design printed on the hall wall-paper also responds to the test for copper. In the bedrooms, there are brass beds, prized by our hostess because they are copper-containing through and through. And the casters on which they and the other furniture roll are brass. Here, too, as in the other rooms of the house, the electric fixtures are brass and bronze and all hardware is made of the same metals. On the dresser is a burnished bronze clock, much more refined than the kitchen alarm but ticking off the same seconds, and this is balanced by a photograph encircled in a bronze frame. Our copper-detecting eye spots a small electric iron, a brush and mirror, numerous pins, the pulls on the furniture, and many other small objects made partly of red metal. The plumbing in the bath-room from shower to drain-pipes, though disguised by a coat of nickel, is truly

brass beneath. In the den of the man of the house, more copper can be found. On the desk finished in bronze there is an ash-tray stamped out of sheet-copper; the paper-cutter is fashioned from a brass rifle-cartridge, a memento of more strenuous times. In the corner a set of metal-headed golf-clubs including a brassie list themselves as containing copper, and the squatty trunk near-by is proud of its brass fittings. Sporting-goods, fish-reels, guns, all show their share of copper.

Even the garden back of the house contains its copper. A fence of copper wire shields it from intruders. The sun-dial, exposed to the sun of summer and snow of winter, like the time-telling devices of the house, has copper in its make-up. The hose-connections, like the pipe that supplies the water, are made of brass. And even the bugs on the roses get a dose of copper when they are maliciously fed paris green, chemically known as copper arsenate. If we use a brass key to open a padlock of the same alloy leading into the garage, it will be seen that copper has been used in important parts of the automobile that this building shelters.

If our search for copper is directed toward ourselves, we discover that the average human being carries a considerable amount of copper around with him. In virtually all of the metal we wear, copper plays an important part. Good pins and snaps are made of brass with a coating of nickel. Belt buckles may be silver-plated over copper or may be made of a copper alloy. The trimmings of our fountain-pen and the case of our patent pencil are likely to be made of brass. The

eyelets in our shoes, as well as many of the nails, are made of the same alloys, and this metal in our present shoes may remind us of the days when copper toes were worn for economy's sake. No matter how genuine the jewelry may be, it contains some copper, if only to harden the gold and cause it to resist wear. Spectacle frames are similar alloys in which copper plays a minor or major part, and cuff and collar buttons are basically copper in most cases. If our profession calls for it we find ourselves wearing brass buttons on the outside of our coats, and, regardless of how we earn our livelihood, brass buttons may attach our suspenders. All of the coins that jingle in our pockets have some copper in them. If we carry a cane, you may be sure that the ferrule is brass either openly or underneath, and the head itself contains at least a small amount of copper. The pocket-knife, if it is well made, is lined with brass and fastened together with pins of the same metal. If the new evening-dress that your wife is designing for fresh social conquests has a metallic shimmer to it, you can rightly suspect that some copper-containing metal has been used in the weaving of its material. And of course the slippers obtain their brillance from the same source. The last covering that is worn by all of us, a coffin, may be of bronze, or may have nickel-plated brass trimmings. If more modern methods of cremation are preferred, a bronze vase will preserve human ashes for centuries.

If we could go back centuries and invade the households of previous ages, there, too, copper would be found serving man. Wires that carry the bottled sunshine of former times would be missing, and we should

feel the lack of electric door-bells and the electric coffee-percolator. But in those days copper found uses to which it is not now put. The mirrors that flattered the flapper were made of the shiny white alloy, two thirds of copper and one third tin, called speculum metal. And before this alloy was perfected, polished bronze itself, was used. Copper itself was prized as an ornament, especially among the races that were living in a bronze and copper age. When knights and ladies were real, not just romantic characters in books, Sunday-go-to-meeting armor was copper or copper-covered. A thousand years before the birth of Christ bronze safety-pins were used, prototypes of the modern ones made of tin-covered brass.

The modern architect, when he designs for combination of permanence and beauty, naturally thinks of copper, brass, and bronze. The best mansions and cottages, built for the future as well as the present, contain much copper in their interior as well as in their walls. Of this practice, it is well to know that the gods of mythology as well as the common sense of science both approve. With spiritual satisfaction one may read in Bulfinch's "Age of Fable":

> Everything of a more solid nature was formed of the metals. Vulcan was architect, smith and armourer, chariot builder, and artist of all work in Olympus. He built of brass the houses of the gods; he made for them the golden shoes with which they trod the air or the water, and moved from place to place with the speed of the wind, or even of thought. He also shod with brass the celestial steeds, which whirled the chariots of the gods through the air, or along the surface of the sea.

CHAPTER XIII

DOING THE WORK OF THE WORLD

For ages copper has been doing the work of the world. As time went on it acquired many new jobs and seldom lost one. As war became progressive, it took brass and bronze out of their menial positions in cannon and cutlass but made them responsible for more modern killing methods. Youthful electricity nearly swamped copper with burdens to carry, and even now monopolizes more than half of its time. A thousand other tasks need copper's aid, and they get it.

Gold is the basis of our fiscal system, we are told. All values are based on the international price of gold per ounce. If gold furnishes the capital for our currency, copper does the labor. But, unlike most cooperations of capital and labor, the relations of copper and gold are never marred by strikes or lockouts. Gold sits in its vaults safe and secure while other metals and paper slave in the counting-houses and on the exchanges, operating in gold's name. Even when the noble metal condescends to venture forth on some special occasion, such as a prize contest, a birthday, at Christmas, or in exchange of actual metal wealth by banks, copper must accompany gold to protect it from the rough usage that it encounters in the world. Silver, the second richest metal used in ordinary coin-

age, also needs copper's protection from the rub of human fingers and pockets.

In every golden double-eagle or eagle, in every silver dollar, half-dollar, quarter-dollar, and dime, there is 10 per cent. copper; they are 900 fine, as the assayer would say. If the names of coins were decided by a majority vote of the metals in them, the "nickel," the American five-cent piece, would be called a "copper," the name given to the penny. The nickel contains only one fourth of its weight as the metal that gives it its name, and three fourths is copper. Once there was a time when the one-cent piece was quite properly named a "copper," as it was made of pure copper. Now "bronze" would be more fitting and true from a metallurgical point of view, as the Indian and Lincoln pennies that are so fascinating to the youngsters of this age are made up of 95 per cent. copper and 5 per cent. tin and zinc. According to the director of the mint, on June 30, 1921, there was $100,384,375.96 worth of minor coinage in circulation, stamped principally from blanks containing copper. This figure represents the face-value of all coins issued since 1793 and not remelted at the mint. During the year 1920-21 the mint spent $437,428.70 for copper to be used for coinage purposes. Virtually every country in the world uses red metal as well as yellow and white in its coinage, and in China and other countries where wealth seldom filters to the bulk of the people the ordinary person hardly realizes that there is any metal in coins other than copper.

Since the very discovery of metal, copper has been used as the medium of exchange. A copper weapon

probably was able to purchase by barter several archaic ones of stone. Later, chunks of metal came to have a definite meaning. An ox was worth some talents of copper, and at each commercial transaction it was necessary to weigh out laboriously that amount of metal. Soon this unneccessary labor became too much, and some ruler of politics or trade stamped his mark in a piece of copper as a sign that he had weighed it and found it worth so much. His people trusted him, just as citizens trust their government, and thus his monogrammed metal became the coin of the realm. It was natural that copper was the common coinage metal, and it was extensively used in the ancient world. Along with iron it was used very early in China, and it also figured in the early Hebrew coinage. Until 269 B. C. it was the sole Roman coinage, and even after that time it continued to play the most important part. Gold and silver, though they cannot get along without a small amount of copper, are preferred as coinage metal as they have less weight and bulk for a certain value. The famous Roman copper coin, *æs grave,* was very thick, with a smooth plain reverse, and was always cast, unlike our modern coins that have their design stamped on a prepared metal blank. They also had the distinction of being worthless for practical purposes as they were made of peculiar alloy that reminds one of the occasional lead nickel that is encountered in our pockets: 70 per cent. copper, 19 to 25 per cent. lead, and about 7 per cent. tin. Other Roman coins were made of copper as pure as the usual casting copper of to-day. When brass was first made, it, too, was turned into Roman coin; one of the earliest ex-

amples was a coin in the time of Augustus analyzing 17.3 per cent. zinc. In point of composition our buffalo nickel has ancestors that existed before the Christian era, Bactrian nickel coins, which contained from 77 to 78 per cent. copper. Medals came into use when rulers wished to honor their subjects by giving them something of intrinsic rather than of monetary value, thus inspiring them instead of making them selfish. Naturally the metal of the minor coinage was well suited to this use, and artistic copper and bronze is widely used to-day as a medal material.

Copper, in addition to taking part in the financial transactions of a people, often acts as a conserver of wealth even when not given the stamp of authority that is necessary to turn it into coin. In Turkey, for instance, says a consular report: "Copper utensils constitute a form of savings bank among the poorer classes. What money they can spare is invested in copper utensils as an addition to their stock, and when they are in need of money they sell what can be spared of their copper according to their needs." And here in America the large value of copper scrap that is rejuvenated each year is proof that the same process of investing money in copper and letting it pay interest by its service goes on whether we realize it or not. A man with a copper roof on his house does have more worldly wealth than one who is sheltered by a film of tin.

To the more valuable metal in the coin, copper acts as a defender against abrasion because of the hardness that it imparts to the alloy. It has also been found that the copper of coins protects the health of the

people. Disease bacteria placed on a piece of paper seem to enjoy life, but when a copper-containing coin is placed on the paper not only the germs beneath it but those all around die from the effect of copper poisoning. There is probably less danger in a youngster putting into his mouth a copper than many other commonly handled things, although the mouthing of coins is not to be recommended.

If you want to buy bronze for industrial use, do not go to the bank and buy pennies. Uncle Sam does not care to have his carefully stamped metal used as bullion, and, what is more important to you, you will be losing money by melting up money. The Government exacts a very large profit on the metal that it turns into coins. It has a monopoly, too, as many in prison will testify. A one-cent piece weighs just forty-eight grains; there are 146 of them to the avoirdupois pound. The value of 146 pennies is $1.46. If one-cent pieces were scrap metal, 14¾ cents a pound would be a very good price indeed, and you would probably have no trouble in getting ten pennies for a cent. With 1000 per cent. profit on his raw material, Uncle Sam can afford to give us the best kind of service and art in the manufacture of coinage. But if the size of the penny fluctuated with the market price of copper, and was worth only its weight in copper, it would not be any more valuable to us in our commercial life; in fact, it would be more trouble on account of the greater and more variable size.

The use of copper in our financial system does not end with the metal of our token currency. Every dollar bill, all the paper money of this republic, and the

stamps that we use in preparing our letters owe their existence to copper. In smooth perfect plates of copper, an artist engraves the figures and lines of our paper money that so confounds attempts at counterfeiting. The money is printed by inking the plate so that the pigment will stay in the indentations and then transfer itself to paper brought into contact with it. Recently modern electrolytic methods have replaced the hand engraving that was formerly necessary in making copies of the printing plates. By very careful application of electroplating, exact duplicates of the master plates are made as often as desired.

For reproducing announcements of high quality, a method is used similar to that employed by the Government in issuing its promises to pay. But copper enters into less expensive duplications, that of ordinary printing by the impression of ink-coated copper, and the illustrations of this book are printed from copper plates. First, in the forms of these letters were cast soft type-metal made largely of lead. Then the resulting type was locked up into pages, and sent to the electrotyper. Soft type-metal printing faces are good enough for job-printing and newspapers where a clear, clean-cut impression is not required, but for book-work copper is needed. A copper electrotype is made of each page and the actual printing done from that. The illustrations are photographed on a piece of copper, and the necessary relief is produced by allowing acid to eat away the light non-printing part of the plate. Shades and shadows of the half-tone are obtained by photographing the picture through a very fine screen, causing the printed illustration to be made

up of very fine dots that are blended into an unbroken picture by the eye. When the book is printed and bound, it may be that letters of gold are selected to proclaim the contents. In most cases the imprints on the front cover and the back are colored with a yellow copper alloy, not real gold, combining inexpensiveness, beauty, and utility.

Copper plates are also used for printing purposes by that combination of artist and printer, the etcher. The etching plate is the medium for a particular kind of drawing whose technique and results are entirely different from those of other kinds of art and printing. Etching is accomplished by the eating away of a substance by acid or other chemical. A plate of copper is first covered with some resistant material, usually wax or resin. Various methods are employed to get an even coat all over the plate: sometimes the "ground" is melted and run or sprayed on, sometimes a solution of it is poured on and the liquid evaporated. When a good coat of ground has been prepared, the artist is ready to begin his drawing. He puts in his lines with a sharp stylus, not merely cutting through the wax but digging into the metal of the plate besides. The proper scratching of these lines is of the greatest importance. The plate must be held firmly and the stylus pushed away from the artist; not toward him, as with the pencil in drawing. The copper dug out of the line is pushed up as a tiny furrow, and this must be of even height if the line is to appear smooth, for it forms the channel that holds the ink. In theory, the etching is not very different from the ordinary zinc line cut used in newspapers. But the

care expended by the artist in making the plate gives a very different result. It is well known that in the line cut no variation in shade is possible. Shadows must be indicated by lines at varying distances apart, or by cross-hatching. The etcher uses the same devices, but he contends that he is able to make a difference in the blackness of his lines by the depth to which they are dug with the stylus or "bitten" with the acid. Certainly, he can make them look blacker by making them wider, and the effect of gradation of light and shadow in an etching is often of extreme delicacy. Having put in the lines as he wishes them, the artist now calls in the acid to deepen his lines and bring out the picture. He uses nitrous or nitric acid. Now, the effect of all acids on copper is unique, and that of nitric acid is the most peculiar of them all. It is no wonder that the artist Joseph Pennell, in a treatise on methods of etching, laments that one never knows how the acid will work; that the same solution will never work in the same way on different days, nor on different plates the same day. The secret lies in the chemical characters of the materials used. The molecule of nitric acid has more oxygen than it is exactly comfortable with, and goes about trying to make some other molecule a present of some of it. The copper is not particularly eager to take it, but is willing to do so. So this transaction is carried out quite aside from the main business which is to form copper nitrate and set hydrogen free from the acid. Then the hydrogen which is set free begins to attract whatever oxygen is at liberty, in order to form molecules of water, and the result is a grand mix-up. All

the molecules show considerable excitement, but whether the copper in the furrows forms the nitrate and moves off into the solution or forms the oxide and settles down where it is, thus hindering the "biting," is left very much to chance. About all the artist can do is to set the pan on the stove if biting is too slow or add some water if it is too rapid. It is easy to understand that a good plate is viewed by its maker with rejoicing. After the lines are bitten to sufficient depth, the wax is removed by dissolving it in turpentine. Now the artist can tone his backgrounds and shaded spaces on which no lines were drawn. A little acid is painted on them with a chicken feather and allowed to remain a few moments. When all is satisfactory, the plate is inked and put into the press, and impressions are pulled. The careful etcher pulls his own prints, and studies each one carefully, for each will differ slightly from all the others. The art of etching is for patient, painstaking men. Not many have succeeded in this field, but those to whom the work is congenial find a never-ending fascination in the vagaries of their chosen medium of expression.

Copper in coins carries value from place to place; copper in printing processes helps to spread human thought; and copper in wires carries human speech. Copper also aids importantly in the physical transportation of goods and passengers.

There once was a time when clipper ships sailed sturdily to sea, copper spiked and copper sheathed. Those ships have ended free careers on the high seas, but many of them are trailing behind puffing tugs, bowsprits gone, hulls defiled by dirty coal. They are

still doing service, thanks to the materials and the manner in which they were built. Sometimes the older generations of ships grow too old in service, their ends come, and they must pass out of this world in flame as wooden ships of our navy and merchant marine usually do. This was the recent fate of the oldest ship of the United States navy, the *Granite State,* formerly the New Hampshire, whose hull was laid down 108 years ago. Through Hell Gate to a lonely beach, the old veteran was towed. There it was burned for the wealth that was in it, the metal that gleams like gold and serves as long. Salvagers greedily took the burnished throne on the poop-deck, and stripped off the hammered copper sheets that had resisted the sea since 1846. Before the Civil War, the frigate *Richmond* was built in Norfolk, also of wood but metaled with copper. The other day the old war-ship quite properly came to the end of its career and was sold for the copper that its hull contained. Twenty-two thousand five hundred dollars was the sum offered by a junk-dealer for the *Richmond.* In the case of two hundred wooden ships built only a few years ago, the offer for each was less than one tenth as much, $2100. At Annapolis there rides at anchor the famous yacht *America,* winner of the international yacht races in 1851, and the brass gear with which she was manœuvred to victory is still giving service.

Marine use of copper was not monopolized by the wise old skippers of the past. The ocean palaces of to-day, though their shells are of steel, need many times the amount of red metal needed by the ships of the past. The modern battle-ship, like the modern

army, feeds and talks on copper. A million pounds of sea-resisting, copper-containing castings, about 500,000 pounds of sheet and tube copper, and about 250,000 pounds as the material for its electrical nerves is the demand of the modern fighter of the seas. Propellers of bronze often require 40,000 to 50,000 pounds of metal. Such a floating city uses copper for all the reasons for which it is preferred on land, with its incorruptibility in the face of the salt of the sea as an added inducement. In the automobiles of the water, the motor-boats, copper is particularly useful for tanks, tubing, sheathing, shafting, rudders, nails and rivets, and all other metallic parts. A forty-five-foot cruiser will contain about 1300 pounds of red metal. Brass and copper are standard for marine use. During the war iron substitutes necessarily fitted a large part of our emergency fleet, but this metal has proved itself unsatisfactory in the face of only a few years' service. The older ships were sheathed with copper to preserve the wood in their hulls and to fight barnacles and other sea life. The same insecticide qualities of copper are utilized in coating the steel hulls with marine paint compounded of the waste copper oxide produced by the copper rolling-mills.

For more than a dozen years a strange craft has been sailing all the seas carrying a scientific crew. The brigantine *Carnegie* is the world's only non-magnetic ship; it was specially built by the Carnegie Institution of Washington to chart the magnetic forces as they prevail over the oceans, so that the mariner's compass may direct him unfailingly, night or day, in cloud, fog, or fair weather. Hardly an ounce of iron

or steel is allowed on board. The hull is of strong white oak, yellow pine, Oregon pine, and teak, fastened with copper and tobin-bronze bolts, composition spikes, and locust-tree nails. Four anchors of manganese bronze, weighing 5500 pounds, are let down by hemp cables through bronze hawser pipes. All the metal-work on the spars, rigging, and blocks of its brigantine rig are of bronze and gun-metal. The hundred horse-power engine called upon when the breezes die is built virtually of non-magnetic metals, chiefly bronze and copper, and the galley range is entirely copper-containing. The boats, two twenty-foot whale-boats and one sixteen-foot gig, are as non-magnetic as the ship itself. For months at a time the crew has lived happily in its non-ferrous boat, making observations with instruments uninfluenced by iron. And in the research centers on land, wherever scientific work is being done, copper, brass, and bronze are valued and used for their many good qualities. Lack of magnetism is only one of these.

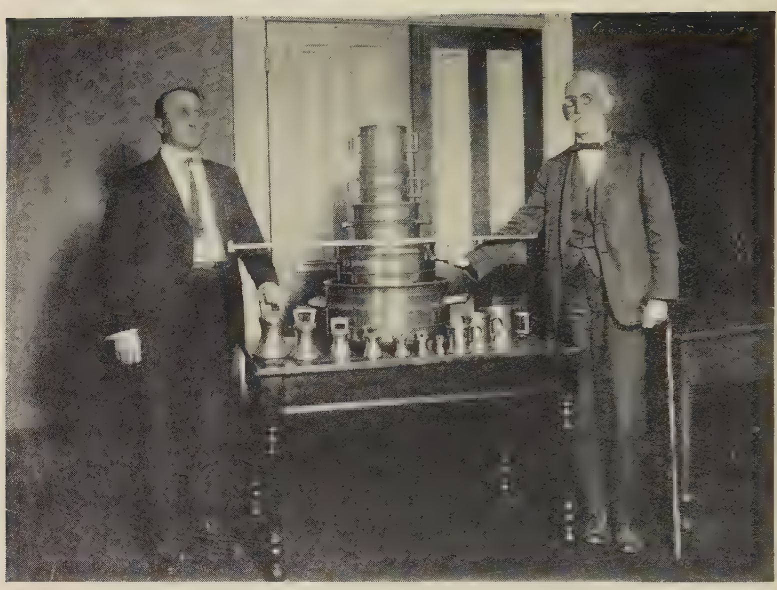
Beneath the sea and in the air, there sail ships which are dependent upon copper. Inside the strong steel shell of the submarine is a maze of intricate machinery controlled through copper and driven by energy that must first become copper-carried electricity. The tubes of the fuel, pump, and trimming lines are copper, and the torpedoes that the submersible discharges have hundreds of copper parts. In the construction of a dirigible, a capital ship of the air, lightness must be combined with strength. As aluminum's junior partner, copper strenthens the duralumin alloy from which the framework is made; and in the case of the *ZR-I*,

constructed by the United States navy, seventy miles of the strongest possible copper wire are being used to tie the sections of the polygonal framework and give it superior strength. The engines of the *ZR-I,* like all other gasolene engines in the world, will need copper in their construction, just as will those of the swifter aëroplanes that will circle about her.

For America's growing fleet of automobiles and trucks, from twenty to two hundred pounds of copper per car must be supplied. Especially in the fuel, lubricating, and ignition systems, copper products are supreme, although in other parts of the car substitutes crept in during the war and the period of keen competition in the automobile field. In one high-grade car, copper is used in the following parts: radiator-screens and oil-screens, aluminum castings (about 8 per cent. copper), valve bronze for cocks, bearings, washers for thrust purposes, tubing for gasolene lines, liners for shims for connecting-rods and other places, connecting-rod pin bushings, on the manifold in the form of wire, asbestos gaskets and brake-linings, nuts and screws in various places, bearings in the clutch throw-out, carburetor (almost entirely of brass), hub-caps, various oilers, bonnet-lock plates and handles, radiators, hinges on the bonnets, wire for the electric lighting and starting system, instrument-cases and windings, primer valves, oil-pipes, number-plates and name-plates, lamps, starting and lighting generators and motors. Each year the automobile industry requires about 150,000,000 pounds of copper, about one thirteenth of the total consumption. It is significant that the easy-going pleasure-cars use less red metal

A BRONZE BUDDHA WORSHIPED BY THE JAPANESE FOR CENTURIES

TRINITY CHURCH, ONE OF THE OLDEST OF NEW YORK'S LANDMARKS, ROOFED WITH COPPER



WEIGHTS DATING BACK TO THE TIME OF WASHINGTON

These weights and measures once used in Virgina are inscribed "County of Fairfax, 1744."

KETTLES THAT HAVE BEEN HISTORY

Both of these tea-kettles date back many years. One of them has brewed tea since 1700.

than the harder-working tractors. One of the largest manufacturers who makes both pleasure-cars and tractors places three times as much copper in the more agriculturally inclined vehicle. Copper license-tags for automobiles are a possibility of the future. Three of the largest copper-producing States, Montana, Michigan, and Arizona, are being urged to show state pride by using non-rusting tags of red metal, and the failure of sheet ferrous metal tags to last their allotted year in several cases has given an impetus to this desire. The additional cost per pair would be about eighteen cents.

The railways of this country, though they do not use a quantity of copper equal to that required for highway transportation, are one of the large consumers. A locomotive for domestic use needs from 1¾ to 2 tons of copper in its construction, including ninety-five pounds for the very essential bell. If this gigantic piece of mechanism is going abroad to do its work it will consume three tons of copper, as European practice usually requires fire-boxes and stay-bolts of copper. Another important use of copper on the railroad is in bearing metal for freight and passenger cars. For this purpose an alloy of about three fourths copper is used, and one thirtieth of the total of the country's consumption is thus used.

Throughout the whole industrial world copper likewise takes part in the alloys of bearing metals, or any parts that may come into contact with friction. Engines of all descriptions need various amounts of it. Another place where it makes itself useful is in parts for pumps and fittings handling all sorts of cor-

rosive and dissolving liquids, such as mine-waters, alcohol, aluminum sulphate, various salts, glycerin, heavy petroleum oils, brine and sea-water, sewage, vinegar, and many others of industrial and chemical importance. In valves for pipe-lines a large quantity of copper finds its calling each year, for, while iron and steel can be used in the pipes, the essential portions of the valves are most safely made of bronze. In the manufacture of food products, chemicals, dyes, candy, and drugs, copper is a metal of importance as utensil material. Copper's high heat conductivity stands it in good stead in this use. When the distillery flourished in this country much copper was used in the worms and stills. Large brewing kettles that made beer in those days now turn out near-beer or ice-cream. Wherever cooking is carried on extensively, as in large hotels or restaurants, copper finds extensive use in kettles and utensils of all sorts. The juice heaters and evaporators of sugar factories are made of copper, and there are copper vats and rolls in pulp and paper mills. Tons of wire cloth are used every week in the paper industry, in the form of Fourdrinier cloth. The liquid pulp is run upon this cloth, and the water drains through the meshes. The cloth has a comparatively short life and is soon valuable for scrap. The wire is made from a mixture of copper, zinc, and tin, containing about 80 per cent. copper.

Electrodeposition has found important industrial application through its ability to build coats of copper upon metal. The newest field for copper coats is that of repairing worn metal parts, such as pump-sleeves, ball-races, and aëroplane engine cylinders.

Through the power of exact duplication that is possessed by electrically deposited copper, the master parts of adding-machines and other such intricate mechanical devices can be reproduced over and over again without harm to the precious standard.

The pin industry, numbering its products by the billion, is virtually the only one in which there is little or no salvage of brass, although it is estimated that two million pounds of copper enter this field each year. Now, copper-containing pins represent only about half of the total number of pins sold in this country, for during the times of copper shortage so-called "steel" pins, made of iron, have made their way into the stores of smaller towns and cities. Some retailers prefer them, as they can charge brass pin prices and make a greater profit on them, but steel pins are likely to rust and damage the goods in which they are used, especially in areas near the sea-coast. Many of these steel pins are sold to those who ask for those of superior brass. Both the brass and steel pins are coated with tin and present the same exterior to the public. Saftety-pins are made of all brass when they are for use exposed to the salt of the sea air, but the best safety-pin is a nickel-plated combination of springy steel shaft, with a brass case to conceal and protect the pin-point.

The cheap alarm-clock ticking on the kitchen shelf and the world's largest clock on the Colgate factory in Jersey City are brothers in the use of copper. If a watch or clock is made to supply the demand for an inexpensive article, nearly all of it will be of brass, but a time-piece that is the best that money can buy will

have gear-wheels and pinions of brass and usually an enameled brass face. The large clock that stares across at New York and can be read three miles off is copper, brass, and bronze from its hands to its wheels. Copper corrects the time of the world just as efficiently as it keeps it. Each hour from the Naval Observatory at Washington a time signal is sent out over thousands of miles of copper wire to regulate electrically wound clocks in all parts of this country.

The same qualities of brass that cause it to be used in time-keeping make it the standard material for the weights that measure our food and clothing and the other factors that enter into our daily life. The national standards of weight stored in a vault at the Bureau of Standards are made of platinum and are so highly treasured that they are rarely used. For practical purposes weights of brass, sometimes nickel-plated, on lever scales with critical parts of brass, are just as good and less expensive. Before the Revolutionary War, Fairfax County, Virginia, placed a set of brass weights and measures in use as its standards. In the following years they at some time fell into disuse, superseded by others fashioned on more exact standards. But the old set, recently unearthed, is virtually in the same condition as when it was first made.

Beside the scales in the shop of to-day there will be found a cash-register to keep account of the copper-containing coins which are taken in during the course of trade. Bills of sale are penciled and corrected with a lead-pencil whose eraser is bound to it with brass. Cash registers consume about one tenth of 1 per cent.

of this country's copper, and the pencils, clips, typewriters, and other equipment of offices consume a smaller but still important amount.

The thousands of articles that fill the shelves of the hardware stores and come within that all-inclusive term of hardware are also avid consumers of copper. Should you get hold of a hardware catalogue on a rainy day you might pick out a list of articles containing copper that would run like this: hatches, jointers, railing, gaskets, valves, pumps, trays, fencing, screens, brackets, kettles, tacks, locks, keys, butts, turns, casters, colters, dot rollers, hooks, levels, chain, lamps, bells of all kinds, vases, lubricators, pans, traps, gongs, brass-plated shoe-nails, candlesticks, plumb bobs, railing fixtures, hose-couplings, hose-clamps, hose-racks, hose-reels, wire cloth, cuspidors, coffee-pots, spikes, latches, oil feeders, ice-box hinges, letter-boxes, hose menders, hose nozzles, rules, copper, brass, and bronze tubing, grilles, copper, brass, and bronze wire, pins, nuts, molds, screws, bolts, scales, pails, gun implements, cartridges, tape-measures, expansion-joints, lawn-sprinklers, boiler-couplings, oil-cans, oil-cups, grease-cups, screw-eyes, wash-room fixtures, percolators, bronze rope, plate, injectors, door-checks, cup-hooks, coat-hooks, screw-hooks, hooks of all kinds, pipes, thermometers, fenders, toy electric cars, staples, copper and brass sheets, catches, copper bottoms, ferrules, nipples, cages of all kinds, pinions, oilers, filters, hinges, washers, padlocks, expansion-bolts, patent letters, show-cases, handles, nails, boilers, gronnets, funnels, soldering coppers, steam-whistles, indicators, lanterns, chafing-dishes, knobs, floor-plates,

bull-rings, pipe-fittings, guides, edgers, water-gages, water-columns, bird-cages, fire-guards, springs, pulls, rivets, torches, horns, shot-shells, burrs, automobile flexible tubing, bronze safety chains, and automobile appliances of all kinds.

When the work of day begins, when noon arrives, and when the end of work has come, these times may be announced by the playing of chimes or the ringing of bells. Bronze, so often used for the purpose that it is called bell-metal, is more important in shape than in composition for rich-toned bells. Usually the copper content is about 75 per cent., but much more concern is shown over the relation of height to width and the thickness of the metal which will determine the note when the bell is struck. The bell industry would not appear to be a very large one on first consideration, yet the consumption of bronze for this purpose during the years 1900 to 1915 ran from 750,000 to 1,000,000 pounds a year. Copper, which has no day of rest from its task of doing the work of the world, often summons congregations to the churches. A typical set of church chimes weighs about ten thousand pounds. It is asserted that bells cannot be made without straw. The molds are lined with a thin layer of straw. As soon as the molten metal is poured in, the straw is charred, but its presence allows the necessary room for a slight expansion of the metal. It is said that neglect of this precaution developed the strains which cracked the Liberty Bell under its violent ringing. Without this defect of manufacture it is probable that not even the excitement of independence could have caused a copper-containing bell to fail at such an important time.

CHAPTER XIV

COPPER'S COMPOUNDS

Copper's universality from a utilitarian point of view is matched by the variety of forms which it assumes in order to do the work of the world. As unaided copper it is preëminently useful; as the major member of numerous alloy partnerships it has many more valuable qualities. As metal or alloy, its rose red, golden yellow, and bronze are both artistic and practical; when united in the bonds of chemical friendship with many of the other elements of this earth, copper produces blacks, blues, greens, browns, and golden yellows that are decorative and industrially applicable.

The brilliant blues and beautiful greens of copper salts have always made them important colors for the painter. A number of copper's compounds are manufactured to-day for this purpose. Blues of two shades are made from the hydroxide and the sulphate; greens are obtained with the carbonate, the familiar mineral, malachite, and the still more familiar Paris green, whose proper name is cupric acetoarsenite. Shades intermediate between green and blue are produced by less common compounds: the arsenite, the borate, and the subacetate. Copper fluoride is used in some blue enamels.

Few of these shades are obtainable from substances

occurring naturally. We do not realize, perhaps, the extent to which the dyes and pigments which make our world a beautiful place are made in man's laboratory instead of nature's. The surroundings of savages are quite colorless beside ours. If we imagine the rude people of antiquity, just waking up to the beauty of wood, sea, and sky, suddenly grown aware of the drabness of their cave walls and tents of dried skin, we understand how paint happened to be man's earliest step in civilization. There were not many colors available for his palette, but the dull reds and yellows of ocher and the blues and greens of malachite, copper, and its associates, with black from charred bones and white from friable limestone, or chalk, gave to the savages that could find all of them considerable play of ingenuity in combining them.

Thousands of years before the earliest recorded history, there lived in the limestone caves of France and Spain a race of people whose drawings and paintings are among the marvels of the world. It is supposed that artists of the ancient Cromagnon race were responsible for making these pictures. To them, then, belongs the credit of inventing paint. While the Cromagnons did not work with greens or blues, it is extremely probable that some early artistic people found the brilliant colors of copper's ores as useful as the more commonplace reds and browns of iron and the white of chalk. Perhaps this happened many thousands of years before metallic copper was achieved; the prehistoric painter may have been the first true user of copper.

Paint in brilliant colors was of major importance in

the personal and tribal life of the American Indian. The redskins mined ocher and hematite ores of iron with which to paint their faces, legs, and bodies a more terrifying red. Red stood for war with them, just as it means revolution to us. But, when a cosmetic that would please the gods was desired, they searched out the blues and greens of the earth, which, unknown to them, carried the same kind of metal that composed the weapons with which they were armed. In their primitive manufacture of face and scenery paint they took the flashy carbonates of copper and ground them fine. These blue or green powders they mixed with gum of the pine-tree. From the yellow squash of the fields they took the seeds, chewed them into a sticky pulp, and spat the binding concoction into the colorful mixture. Thus was Indian paint made to be spread on bodies and offerings to the great spirits. For the Indian, copper painted the sky of his altar blue, it gave the growing green color to his pictorial vegetation; all that was good and spiritual was represented in the green and blue of copper's compounds.

When historic times at last came to the earth, we find the Egyptians decorating their buildings with fresco-like paintings. Their pictures were made on plaster, but were for the most part line drawings filled in with colored wash, not shaded. Ceilings, especially of the temples, were made to represent the sky and dotted with five-pointed stars, painted in yellow on a blue ground, azurite pigmented. In the years that have since passed, the surface of the sky has turned to a green film of malachite, but when this is scratched the original sky-blue shines through. The Greeks

used paint, much of it copper, on their buildings, and especially on their statues. The latter were made to look as lifelike as possible, and the hair was often gilded with pure gold. The statue's armor was real, made of bronze and fastened upon the figure.

In the middle ages came a great development of picture-painting methods. Artists began with wall-painting, and learned to apply pigment to wet plaster as fresco. This is the only branch of painting where a vehicle for the pigment is not needed, for the colored substances combine directly with the plaster. Care is necessary in the selection of pigments for such works, for the chemical action between some pigments and the lime gives very unexpected colors. Wooden walls, as well as plaster, were adorned by medieval artists, and after walls they turned to specially made panels upon which their pictures could be moved from one place to another. Only at a very recent time were wooden panels replaced by the artists' canvases with which we are familiar. Painters until recently ground their own colors in oil carefully by hand, or let their apprentices, who were learning to be artists, do it. The same principles are used to-day, although grinding and mixing are done mechanically, and paints for every purpose may be bought ready for your brush. The staple pigments are still the same as those used by the artists whose works have come down to us through the ages.

Of nearly the same antiquity as the art of picture-daubing is that of pot-making. The troglodytes who drew the deer and bison upon their cave walls may very well have possessed only stone knives for their

household equipment, and have eaten their chunks of venison from the cave floor. But man did not advance very far beyond the status of the beast before he discovered that he could fashion sticky wet clay and dry it in the sun or by the camp-fire and so add to his appurtenances a line of pots and pans which were immensely useful for storing food. The earliest kinds of pottery were simply dried mud. But even with such simplicity there was opportunity for interesting variety.

Copper ores, as we have seen, have the deceptive habit of staining green the near-by ground. It is possible that some early savage living near such a copper deposit may have used this tinted clay for a bowl to grace a chief's banquet-table, or to hold bloody libations to some crude devil-god. But, if so, the vessel has perished. We cannot connect the use of copper salts with early unglazed pottery. Red, buff, black, and, more rarely, white are the only colors exhibited by such ware.

When the curtain of history rises on ancient Egypt we find the potters already so far advanced that they possessed the art of glazing. Although their pottery underneath was poor stuff containing scarcely any clay, they applied a beautiful turquoise blue glaze, whose color is due to some copper salt. The Egyptians made the older styles of pottery also, but this blue glaze seems to have been their own invention. It was developed as time went on; different salts were used from time to time, giving varying shades; decorations in other colors, notably the dark purple or black of manganese, were placed upon its surface; and the

blue glaze was even added to objects made of stone.

From Egypt the ceramic art spread on the one hand to Greece, and thence to Europe, and on the other to Asia, where it has flourished not only for utensils and works of art but for architectural purposes as well. Whole temples in India and China are faced outside and in with beautiful polychrome glazed tiles, with the blues and greens of copper salts always much in evidence.

The vases and other articles of Greek pottery were decorated with surprisingly few colors. This is somewhat disappointing after the large number of colors used by the Egyptians. But the remarkable quality of Greek ceramic ware lies in the beautiful workmanship which its makers put into the common materials that were at hand. Ordinary red or yellow ocher colored their clay, but they refined and mixed it with greatest care, and produced vases of beautiful red and orange colors. For a long time the Greeks used as decorations only a black coating, whose composition is not definitely known, laid on like paint. Much of their finest work was done in red and black only. Polychrome work was made, however, to some extent. The vase was first given a coating of fine white clay, which was fired, and then the figures were put on with purple, yellow, blue, and green. The latter colors are believed to be due to artificial compounds of copper and were not fired after they were put on. Vases of this character were made about the fifth century B. C., at the time when Greek ceramic work was at its best. Some blue-glazed work, of the same character as the Egyptian, was made, also, and, quite late, lead glazes

colored green with copper oxide appear in the relics of Greece.

When Rome succeeded Greece as the leader of thought of the ancient world, Greek ceramic art had reached a period of decadence. It was being replaced in popular favor by metal dishes, which had then become cheap enough for fairly common use. The potters, however, saw an opportunity, and made their ware as much like the more expensive metal dishes as they could. Such vessels were no doubt sold to poor people with the assurance that they were "just as good as metal."

Other colors than green or blue are added to fired clay by copper. In combination with other oxides copper helps to produce enamels of black. On old Chinese porcelains a peculiar red glaze has been found, called Chinese red, *sang de bœuf*, or ox-blood, and this has been found to be due to tiny particles of metallic copper formed in the glaze by reduction of its copper oxide during firing. The same reaction is used to-day to make the best ruby glass for signal-lights.

The next development in the use of copper in ceramics came from the Mohammedans in Spain. Eastern peoples had invented the "luster" glaze, in which a thin film of silver fired with the glaze gave a beautiful iridescence to the surface. The Saracens adapted copper to this process in place of silver, and obtained luster of the rich metallic copper color. Copper sulphide was used as the paint, and reduction to the metal was effected during the firing by applying vinegar, ocher, and wood smoke.

The very beautiful majolica ware was produced in

Italy during the late middle ages and the Renaissance, first in imitation of the Moorish and Chinese ware that came into the country in commerce, and then acquiring an individuality of its own. Famous china, stoneware, and porcelain centers soon appeared throughout Europe. Their products, though differing in shape and decoration, were all of the same general style of manufacture, painted decoration often in copper's blue and green on a white, opaque tin enamel.

Another new development in pottery, the Wedgwood ware, arose in England in the eighteenth century. It differed from its immediate predecessors in being unglazed, yet impervious to water. Its geniuses were Turner and Wedgwood. In type, the ware is a porcelain body, made from very fine, plastic white clay, and mixed with barytes. Color is then introduced in the form of those metallic oxides which have always been used in ceramics. Clay figures of white or a contrasting color are molded and pressed on, and united to the tinted background by firing. Many of the designs are adapted from the charming decorations on Greek vases.

The history of copper salts as decorations in ceramic manufacture is about complete. First the colored glaze was used, then decoration under a transparent glaze, then the combination of painting the body and covering it with a tinted transparent glaze. With the introduction of opaque white tin glaze, the decoration was applied over it. Metallic luster followed. Then the potters' attention turned back to the body of the ware, and, for a time, decoration of unglazed "biscuit" was developed. Modern china and porcelain quite

generally have reverted to decorated glazed ware, yet no one can assert that entirely new forms of ceramic ware may not be in store for potters of the future. The colors now in use in this industry were probably known also by the ancients. Chief among them are cupric oxide, which, though black, gives green and blue colors when burned on stoneware, faience, porcelain and glass; and cuprous oxide, which is responsible for beautiful shades of red in glaze and glass. Cupric fluoride is used for blue, and cupric acetate, or verdigris, for green. Porcelain painting draws on one more member of the family, cupric borate.

Another primitive industry with which copper's compounds have long been associated is textile dyeing. Copper salts themselves are of little importance as dyes on account of their solubility, but the metal enters into calico-printing processes as a mordant in the form of subacetate, chloride, chlorate, and sulphate; as basic cupric chromate and cupric ammonium sulphate; and also in its metallic state as part of the printing machinery. In Egypt, in Rome, and, since medieval times, in Europe, designs were applied to cloth by hand from small wooden blocks which had taken up a little dye from a moist dye pad. The block was alternately coated with dye and pressed against the cloth, very much as one uses a rubber-stamp. An improved printing block had copper inserts in the face to make it more durable and the design sharper. Of course, material dyed in this way was very expensive, for its printing was laborious and exacting. Printing in several colors was practised, although each extra color meant another block and dye-

pad and additional painstaking work. In the last century, when machinery suddenly took upon itself the drudgery of the world, one of the most widely acclaimed inventions was the calico-printing machine. It not only printed at an amazing speed, but was so arranged that the dyes and mordants, in the form of paste, could be fed to the exact spot where they were wanted and many colors could be printed at one time. Hence come the chintzes and calicoes of our grandmothers, and, by the same process, the fascinating variety of printed cottons and silks in the shops of to-day. Copper has played its part in the development of this industry, too, for the little copper-rimmed blocks of the hand presses have given place to engraved printing cylinders of that same metal.

In straight dyeing, copper finds its chief use in one of the receipts for black. But a more important use for it is as an after-treatment for cotton colored with certain classes of dyes, since a bath in copper sulphate makes those dyes fast. "Coppering" was prescribed in a handbook by the German dye monopoly, the Badische Anilin und Soda Fabrik, before the war as a necessary process in dyeing the brilliant fezzes for the Turks.

The three industries just described as needing large quantities of copper's compounds are among the oldest of human arts. Another art, predecessor to the modern science of medicine, must take its place in the history of uses of copper salts. That art was known to its practitioners as "iatrochemistry." It was a more modern, a more intelligent, and a more scientific outgrowth of alchemy. The iatrochemists set about

the systematic study of such chemicals as they knew, and were particularly interested in their effect on the human body. They were the first in modern times to explore the field now known as physiological chemistry. Their influence persisted long after their formal doctrines were outgrown. One of their ablest successors was Johann Rudolf Glauber, who was born in Bavaria in 1604. He, too, was interested in compounds and their properties, and was the chemical discoverer of a number of metallic salts, among which was copper sulphate. He was not, of course, the first human being to see this compound, for it was well known to Roman metal-workers, and was described by Dioscorides as pieces "shaped like dice which stick together like grapes." But Glauber prepared it in a laboratory manner by dissolving copper in sulphuric acid, studied its behavior, and, as it were, introduced it to lay society. We do not know whether the Romans used blue vitriol as a medicine or not. We are not certain that Glauber did, but in view of his interest in medicinal salts, we may be fairly sure that he tried it on somebody. At any rate, after Glauber this salt took its place among doctors' prescriptions.

Copper in other forms has also been used medicinally. Both Dioscorides and Pliny refer to "flowers of copper" as a valuable medicine. According to Dioscorides, they are formed by pouring cold water upon molten copper, whereupon "the copper spits and throws off the flowers." Pliny has them formed by air instead of water: "The flowers of copper are used in medicine; they are made by fusing copper and

moving it to another furnace, where the rapid blast separates it into a thousand particles, which are called flowers.'' He describes two other substances, *smega* and *diphrygum,* which were also formed as by-products of copper smelting and used similarly. They were probably all the same substance, whatever it may have been.

Modern medicine makes use of verdigris, copper acetate, in diseases of the skin, and still uses copper sulphate as an astringent and an emetic. Physicians to animals also make use of it. The dose for human beings is specified as 0.25 gram, with the caution that ammonium salts are incompatible with it; the veterinary prescriptions are similar. Horses get from four to eight grams, and cattle from four to twelve. Sheep and hogs take about the human dose, 0.3 to 1.3 grams, and dogs need only 0.016 to 0.13 gram. Its use internally is not free from danger, for all copper salts are poisonous to some extent. It is now more commonly used locally as a caustic and antiseptic.

Although not far removed from medicine and hygiene in our thoughts to-day, insecticides are a much more recent product of human ingenuity. Man has only lately awakened to the fact that he has to fight for his very existence, not against horrendous dragons nor human foes, but against that part of the earth's population to which he refers scornfully as ''bugs.'' These creatures destroy our food, spoil our crops, kill our trees, damage our houses, devour our warm clothing, even invade our tissues and produce disease. Our most deadly poisons must be drafted into chemical warfare against them. The rather slight toxicity of

copper salts makes them the standard agricultural insecticide, for they will kill harmful insects without injuring the plants or spoiling the food value of their fruits. Paris green and Bordeaux mixture are the two familiar chemical friends of the farmer. Arsenic joins its more deadly properties to copper in Paris green, cupric aceto-arsenite, to war on worms and larvæ. Bordeaux mixture is lime, copper sulphate, and water, and is the great enemy of caterpillars and moths. Other copper salts similar in nature to these two are also used for the same purpose: verdigris, copper subacetate, cupric arsenite, and cupric ammonium sulphate. The "white disease" of grapes is treated with cupric fluosilicate.

Copper sulphate is also death to algæ, the small green plants that at times have produced an unpleasant taste in the water of several large cities. Large quantities of the salt are needed to remove this taste and to kill the bacteria, although only two pounds of copper sulphate are used to the million gallons of water. Other aquatic troubles are being conquered by another copper salt, the oleate. It was recently discovered that if fish-nets are cured by impregnating them with this salt it discourages even those marine pests whose appetite for twine is unaffected by the coating of tar usually employed.

Minerals, of course, are the compounds which we find already formed in the earth. We have seen that their chief use is as the source of the metal which we find so valuable. But some of copper's ores are so beautiful in their bright colors and regular markings that they are set apart into a department of mineral-

ogy whose importance varies greatly in people's minds. They are used as gems. A gem is purely an object of beauty. It has little intrinsic value. Not all gems are mounted by the jeweler, for the mineral enthusiast usually makes his own collection of finely crystallized, or rare, or beautifully colored specimens whose only use is to delight the eye. Almost any one of copper's ores would add interest to such a collection. But the lapidary usually cuts and polishes only malachite, the carbonate, or, more rarely, its close relative, azurite. He has his own standards for judging a mineral's fitness to enter the ranks of jewels. Each of its qualities of individuality must meet his requirements. Color and luster are characteristic properties of greatest importance to the gem collector. Hardness not only aids the scientist in recognizing minerals but determines for the jeweler the wearing qualities of those minerals when used as ornaments. Mineralogists have adopted a series of ten minerals of graduated hardness to serve as a scale for measuring this property. They are, from the softest to the hardest: (1) talc; (2) gypsum; (3) calcite; (4) fluorite; (5) apatite; (6) orthoclase; (7) quartz; (8) topaz; (9) corundum, the mineral name for both ruby and sapphire; (10) diamond. The mineralogist, to remember the scale, takes a leaf from the book of the sure-fire memory expert, and makes up the first letters of the minerals' names into the fascinating word "tagycaflaporquatocodi," but he does not carry samples of the ten with him when he goes out prospecting. His equipment then for testing hardness consists of his finger nail, with a hardness of 2; a copper cent,

which scratches in Class 3, the blade of his pocket knife whose hardness is 5; and, if he expects to encounter objects in the ruby-diamond class, a quartz crystal. Each of these standards can scratch all the softer ones and can in turn be scratched by those that are equal to it or harder than it is. Metallic copper will scratch gypsum and calcite, but it is scratched in turn by calcite and fluorite. Malachite is a little harder, corresponding to 4. For that reason it is not a more important gem stone, for the lapidary prefers more durable minerals whose hardness is greater than 6. Malachite and azurite can be used only where not subject to wear. In this country, where most gems are made into personal ornaments, these minerals are not as important as in Europe. Before the War the beautifully banded malachite from Siberia was made up there into vases, boxes, and even objects as large as mantels and tables, and was also used in mosaics. Opinions about the use of minerals as gems differ greatly. Many mineralogists, on the one hand, look upon interest in jewels as a regrettable survival of barbarism. The opposite extreme is the veneration of these shiny baubles for the magic powers which superstition has given them. Malachite had its share of virtues attributed to it by the ancients, centering chiefly in marvelous medicinal properties. The mere wearing of it was believed to ward off dangers and disease. It would make children grow and prevent convulsions. If they had colic, they had only to swallow some powdered malachite to become well. But the mineral's most remarkable power was said to be as an anesthetic. The "Speculum

Lapidum" has it that malachite "being taken in drink or bruised in vinegar and applied to the members that are to be cut off and burnt, it makes them so insensible that they feel scarce any pain."

Minor employments of the salts of copper are found on every hand. The great electroplating industries have the waters of their tanks colored blue by copper in solution, for the sulphuric acid which conducts the atoms of the metal from anode to cathode turns them to copper sulphate on the way. In electrolytic refining, the impurities in the crude copper anodes also go into solution in the acid, and are not precipitated out on the other side, and so the tank water must be drawn off from time to time when it grows too impure. This liquid is one of the sources of commercial blue vitriol, which is one fourth copper.

The chemist in his laboratory finds a variety of uses for the salts of copper. One of the commonest is the employment of cupric oxide as a source of oxygen in his combustion furnace. A similar use is the separation of a gas like oxygen, which will combine with copper, from one like nitrogen, which will not. To do this, the chemist allows the mixture, in the above case air, to pass through a hot tube containing fine grains of the metal. This is the first step in isolating the rare gases of the atmosphere. Copper sulphate's insistence upon taking up water to build into the structure of its crystals is cleverly used to remove small amounts of water from organic liquids in which the salt does not dissolve. This is particularly useful in the case of alcohol. Absolute, or dry, alcohol is a valuable solvent, but it boils at a higher temperature

than a mixture of 95 per cent. alcohol and 5 per cent. water. Ninety-five per cent. alcohol is therefore the purest that can be got by distillation. It is shaken with quicklime until nearly all the water has been extracted; then it is filtered, and some dehydrated copper sulphate is added to it. This salt is quite colorless. The characteristic blue color does not appear until it takes up water of crystallization. Alcohol in which a fresh sample of anhydrous copper sulphate remains white is absolute. One other important reaction demands copper. It is a test which distinguishes the simple sugars like glucose, milk sugar, and the fruit sugars from the more complex cane-sugar and from starches. Fehling's solution, which is made of copper sulphate, acid potassium tartrate, and sodium hydroxide is added to a solution of the carbohydrate, and the mixture is boiled. The complex substances do not change the solution, but the simpler sugars break it up, and a precipitate of bright red cuprous oxide forms in the blue liquid. The amount of oxide formed is a measure of the amount of reducing sugar present. A still different occupation of copper in the laboratory is as a catalyst, one of those subtle persuaders which the chemist calls in to set a reaction going when it will not go for him alone. And there are still many more ways in which copper and its compounds make themselves useful to the chemist, which cannot be told.

Copper salts in great numbers have been used in photography on an experimental scale, but their greatest uses to man seem to lie in other fields. Cupric nitrate is, however, used to some extent in the prepara-

tion of light-sensitive papers. A few other uses of some of copper's compounds merit some notice, not so much for their importance as for the unusual things we find them doing. Cupric abietinate, a compound of copper and resin, protects wood from insects and decay. Barnacles are discouraged from taking up their abode on ship bottoms by a very similar compound, cupric resinate, and also by cupric and cuprous sulphides incorporated in the paint. Fireworks frequently employ copper carbonate to make their green fire, and other copper salts are sold to be sprinkled on the fire in the home to remind one of the colors of burning driftwood. The salts do not really burn, even in fireworks; they volatilize in the flame of other substances and give it a green color. But copper phosphide, a relatively unstable compound, can be made to do even more spectacular things. Mixed with potassium and cuprous sulphides, it becomes explosive, and may be used as a primer. The mixture is known as Abel's fuse.

Another unusual use of copper sulphate will delight the motorist and highway engineer, since when 3 per cent. of this copper salt is added to the usual asphalt concrete it seems to keep the road surface from "running" when exposed to the heat of the sun in summer. The United States Forest Products Laboratory has recently found that copper salts improve casein glue, not only in stickiness but presumably in color as well, since the report speaks of the violet glue which results. Sometimes, sad to say, copper salts are even found in conspiracies to defraud. Cupric chloride may perhaps find mitigating circumstances to excuse its ap-

pearance as a sympathetic ink, and some people may like their white marble dyed blue with cupric fluosilicate, since it is thereby hardened as well, but what can we say when we find cupric stearate bronzing plaster statues and sedate copper sulphate parading itself as a hair-dye?

CHAPTER XV

THE BRASS AND BRONZE OF WAR

Important as copper is in peace, it is more important in war. A man can not be killed in an up-to-date manner without copper. Supplies of copper are as necessary as drafts of men, and the nation without sufficient brass or bronze with which to equip its men finds itself in an unpleasant predicament. "The nation that goes to war without a good stock of copper is worse off than it would be without a board of strategy," it has been said. This is indeed true; wars have been won despite a surprising lack of military sagacity, but no conflict of any consequence since the fashioning of the first copper battle-ax has occurred without red metal fighting in some way on both sides. The rations of war are copper, brass, and bronze as well as iron, coal-tar, wool, wheat, and gasolene.

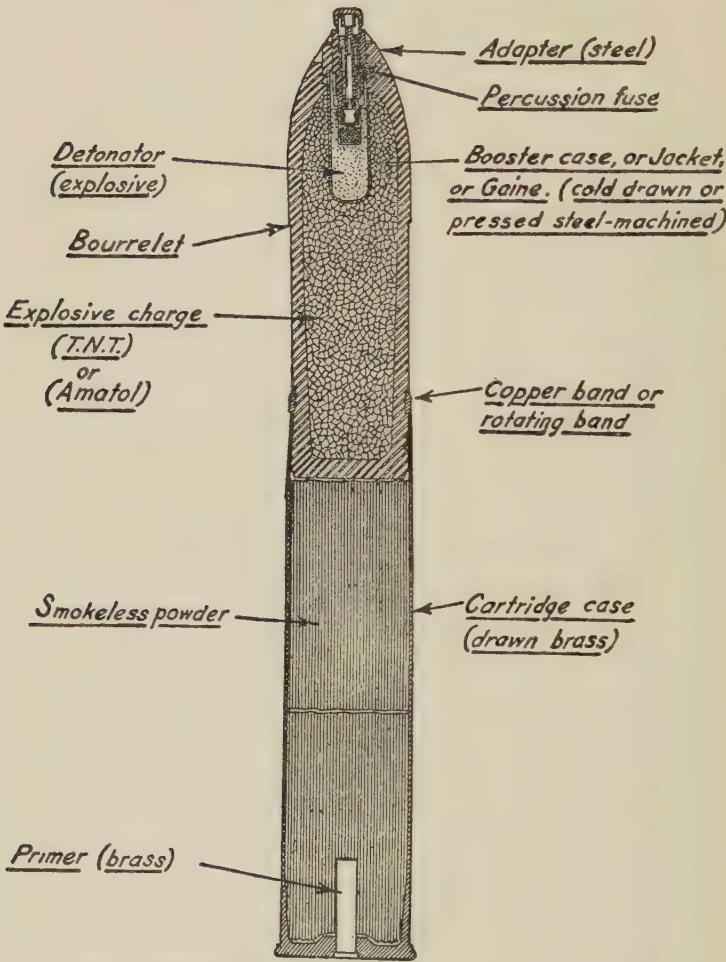
Long before America entered the World War, long before the war clouds over Europe broke in 1914, copper was in the service. In arsenals, in munitions, in uniforms, in the products of peace that can be applied to war, copper was stored, purposely or unintentionally, ready to be called upon in the event of war. When the war began in Europe the demand for copper was temporarily slackened by interference with normal trade, but only a few months were required before the greediness of war and its taste for red

metal began to show itself. America began to get munition orders; equipment and material for modern war meant large quantities of copper.

Then at last April, 1917, came, and America entered the war. The copper industry virtually enlisted itself along with the youth of the country. Its peacetime jobs had to be left to others of the metallic family. As a president of a large copper company has said:

> I sometimes wonder how many people understand the fields which copper and brass abandoned in a few hours in order to do its part in war service. In a score of industries representing an annual consumption of copper and copper alloys running into hundreds of millions of pounds, an almost disastrous condition was created. There was no copper for them. The government needed it all and none was disposed to question its right to all that could be produced.

That sacrifice was made, and all that was in copper was injected into the war. New mines were opened, new smelters were built, and night and day the mines and reduction plants poured forth the red metal that in war is more precious than gold. Between the prewar year of 1913 and the peak war year of 1918 copper production in the United States increased by more than one half, and throughout the world, in warring as well as neutral countries, production was so much stimulated that the world total was increased by about the same percentage. This metal went through the refineries at a greater rate than ever before. In the munition factories most of this copper was used. Nearly all of the metal in the small arms ammunition that



From "America's Munitions"

SKETCH SHOWING THE WAY IN WHICH COPPER AND BRASS ARE USED IN A 75mm. SHELL, HIGH EXPLOSIVE NOSE, FUSE TYPE

plays such an important part in the fighting is composed principally of alloys of copper, and cases for artillery shells are made of brass. Each steel projectile of big caliber is accompanied by a band of copper in its flight toward the enemy.

Take the .30-caliber service cartridge that is the mainstay of the American army. Billions of these were made during the war, and the peace-time production was 100,000,000 a year. The bullet is incased in a heavy metal jacket of cupro-nickel, an alloy of about 85 per cent. copper and 15 per cent. nickel. This combination is used instead of steel because very hard metal will wear out the delicate rifling of the gun-barrels, and iron-containing metals will rust and become useless. Cupro-nickel is not hard enough to damage the rifling excessively and yet is sufficiently strong and hard to keep the interior slug of hardened lead from deforming and running out of its case. Germany, pressed for red metal that it cannot mine at home, used a bullet with sheet-steel jacket, but even this attempt to do without copper entirely failed, for the coat of copper had to be added to the bullet's exterior to preserve it from rust and soften its contact with the barrel. So fast was the manufacture of munitions draining America's copper supplies that army engineers experimented and perfected a similar steel copper-coated bullet, that would have been put into production if cupro-nickel supplies had failed. No satisfactory substitute for brass cartridge-cases and shells has been found. Experiments have been made with steel, but, in addition to being liable to rust, they are too expensive. The shell-cases of both

the rifle, machine-gun, and pistol ammunition and of larger artillery rounds are made of a brass containing about 70 per cent. copper. Brass is used for this powder container because pure copper, while tough, has not enough resiliency to spring back to the original form after being thrust against the chamber walls of the rifle by the high gas pressure developed in the firing. The chamber pressure of a military rifle is often higher than 50,000 pounds to the square inch. If the case does not spring back on account of being too soft, or if the rifle chamber is the least bit pitted, the shell-cases will be smeared upon the chamber walls and can not be extracted easily to give way to a loaded shell. And if the shell is too hard and brittle it is likely to split at the neck or break off at the base. For these reasons the brass shells must be manufactured with great care; the temper and gage of the finished case is very important. Cartridges used on the rifle-ranges in peace and often those used in actual battle are salvaged and used many times over. Specifications for United States cartridges require that they stand twenty reloadings without failure. This results in economy, as the pre-war cost of an army cartridge complete was 2½ cents, and the brass case accounted for 1½ cents of that amount.

Every portion of the complete cartridge except the powder charge contains copper. The primer cup and the anvil, upon which the firing-pin falls as the first act in the series of episodes that occur in firing a rifle, are made of copper. Even the clip which holds five cartridges together so that they can be handled easily and loaded quickly in the rifle is stamped out of sheet-

brass. In the manufacture of a cartridge-case flat disks are stamped out of sheet-brass as the first operation; the next operation consists of forming a cup of the disk. In the successive operations the cup is gradually drawn out into a cylinder, and the cylinder in the final operation is "necked down" to suit particular requirements. After each drawing process the case must be annealed, as the mechanical work done on the case during the draw makes it hard and brittle. As an intermediate step during the drawing operations, the head is formed from the thick metal left in the base.

When the war began only the ordinary type of bullet that has been described was standard for American ammunition. New methods of fighting brought the need for new kinds of bullets. An armor-piercing bullet was perfected by replacing most of the interior slug of lead with very hard steel. A tracer that can be followed by the eye in the brightest sunshine was made by partly filling the cupro-nickel jacket with a mixture of barium peroxide and magnesium. For incendiary purposes, phosphorus was loaded into the jacket in such a way as to bestrew itself over the landscape when fired. As in the common service-bullet, the copper-containing jacket is an essential in all these new forms.

For the service-rifle and ordinary machine-gun, the .30-caliber cartridge was used by our forces, but for automatic pistols and revolvers .45-caliber ammunition was made. Need for machine-guns shooting large bullets was felt, and some eleven-millimeter ammunition, about half an inch, was made for them.

But in the manufacture of these cartridges the methods of .30-caliber ammunition were used and copper played the same important part.

It is estimated that the ordinary rifle cartridge will contain from 23,000 to 28,000 pounds of copper in a million cartridges, depending upon the make of rifle. During the nineteen months of warfare the American production of machine-gun and rifle ammunition was 2,879,148,000 rounds, and during that period England produced 3,486,127,000 rounds, and France 2,983,675,000. It is estimated that these cartridges alone, excluding any of the other war uses of copper and the cartridges manufactured earlier and after the war, consumed about 243,000,000 pounds of copper, nearly one fourth of the toal domestic consumption of copper in this country in 1920.

The cartridges for the smaller sizes of artillery are simply overgrown rifle-cartridges in their appearance and construction. The bullet of copper alloy is replaced with a steel shell, but copper still guides this projectile to its mark. A ring of copper encircles the shell near its base. This not only allows it to follow the rifling of the gun and acquire the twirl that keeps it straight in its flight, but it keeps the gases of the explosion from creeping out past the shell to impede rather than help its travel. These copper rotating bands will average two and a half to three pounds per shell. When artillery must fire quickly and the charge is small enough to be carried in one package, the same sort of device for inserting powder and projectile into the gun is used as for the rifle. The larger cartridge-case is also made of brass; the principal

Courtesy of Ordnance Department, U. S. Army

EVOLUTION OF A RIFLE CARTRIDGE

View showing successive stages in the manufacture of primer, case, bullet, and clip for .30 caliber U. S. Army rifle ammunition. All of the parts contain copper. The top row shows the development of the primer cup and anvil. The second and third show the development in the manufacture of the cartridge-case. The fourth row shows the development of the bullet. Completed cartridges are shown in the next row, and the bottom row illustrates the steps in the manufacture of the brass clip that holds the cartridges together.

U. S. Signal Corps Photo

A DUMP OF EMPTY .75'S

Each one of these brass shell-cases has discharged its powder and shell in actual warfare in France.

DISTINGUISHED SERVICE CROSS

A medal of bronze, symbolizing the highest honor bestowed by the United States Government exclusively for bravery on the battle-field.

difference is that the rifle cartridge-case weighs a few ounces and the gun shell weighs pounds. The following list of weights of brass shells will give some idea of the quantity of copper used in artillery ammunition:

	Caliber in Millimeters	Length of Case in Inches	Weight of Case in Pounds
3-inch field-gun	75.29	6.220	1 lb. 5 oz.
3.2-inch, U. S. army	81.9	13.300	4 lb. 2½ oz.
4-inch	100.4	28.575	10 lb. 13 oz.
4.72-inch	119.	34.840	16 lb. 8 oz.
5-inch	126.2	34.875	18 lb. 1½ oz.
6-inch	157.2	41.60	28 lb. 13½ oz.

For every gun in action there must be piles of loaded shells. The famous seventy-five millimeter gun can open up with a prolonged fire at the rate of one shell every ten seconds; in case of necessity one shot every three seconds can be achieved. Tons of brass must back up each artillery battery.

In many ways copper enters into implements of war other than ordnance. One of the American achievements of the World War was the radio telephone through which aviator could talk to aviator or to a ground station. As with the many radio sets erected for pleasure to-day, without copper, radio in war would have been impossible. Miles of telephone and telegraph wire went to France with all their copper-containing accessories. The green color of rockets and the other signal pyrotechnics of the battle-front is given by salts of copper. In the ranks of the Signal Corps in France there were 15,000 pigeons who succeeded in delivering 95 per cent. of the war messages entrusted to them, attached to their legs in a tiny

capsule. Bands of pure copper held these messages securely to the birds' legs after aluminum had been found to be too easily broken. Copper enters into the manufacture of nearly every major article used in warfare; it formed parts of the bearings, fuel, and ignition systems of the Liberty aviation engine and the horse-replacing auto-trucks; it conveys electricity to the great search-lights; and the latest type of trench knife designed by the A. E. F., like the knives of old, had a bronze hilt. Military locomotives utilized red metal for their fire-boxes; doughboys wore identification-tags made of a copper alloy. Brass buttons once were symbolic of the military. In recent years the shiny brass has been dulled to bronze for fear that its reflection would draw fire and death, but copper still adorns the uniforms. In the field the dull businesslike insignia that symbolizes the authority of officers are made of metal containing copper; in happier times the "gold" braid of full dress that enhances a military ball is really spun brass or bronze. In the war-ships at sea, in the supply-ships that serve the fighting forces, in all the equipment of the great civilian army at home, vastly outnumbering the fighting forces, red metal plays its part in war.

Even in peace, when the war has been won and the country sickens at the thought of hostilities, more than twenty million pounds of copper are being used in ammunition each year. Shot-gun shells of ordinary manufacture are made of paper with a brass end or cap, about five million such cartridges are made each day in the United States alone. Numerous other cartridges, ranging from the small yet effective .22-

caliber B.B. cap to the sporting counterpart of the high-power military rifle cartridge loaded for bear, are added to the total.

The United States had copper enough for the war—not a superfluity, but sufficient for actual needs and a reserve for the future if the war had been prolonged. America's copper mines and smelters produced as never before and fed the armies of our allies as well as our own. America's resources may be visualized from the fact that after the War the Government was able to turn back into commerce about 100,000,000 pounds of copper and brass that had been purchased for war purposes. This was nearly equivalent to one normal year's consumption of the munition industries of this country. Still you may read in the technical periodicals of the War Department offerings of heavy tonnages of copper and brass to be sold by bids. The qualities are still sizable, as typical items show: 862,107 pounds copper ten-inch rotating bands; 396,305 pounds copper eight-inch rotating bands.

Copper in Germany during the war has quite a different story to tell. The Central Powers have always been lovers of copper and copper products. Germany has held a unique place among the world's copper consumers, as her per capita consumption exceeded all others and her production was very low. A great variety of copper-containing objects were manufactured and used, and the most popular type of building front was sheet copper or bronze. Now Germany and Austria are virtually denuded of all removable copper, brass, and bronze; it has been sacrificed to war. At the outbreak of hostilities Germany held

enormous stocks of copper, and to these the Government added within three days all the available copper in the neutral countries of Europe, buying at the instigation of the great German organization, the Allgemeine Elektricitäts-Gesellschaft. First of all, Germany ran short of nickel and platinum, and then came a shortage of copper and brass, which grew more and more acute as the war progressed. The war lords requisitioned all the copper that they could lay their hands on. Kitchen pots and pans, faucets, door handles and knobs, locks, brass fixtures of all sorts, mortars and pestles used in the home for crushing sugar and spices, ornaments, statues, locomotive fire-boxes, and even church-bells were seized and melted down to make shells and bullets. Museum relics and scraps were treated alike. From the church-bells alone 30,000,000 to 40,000,000 pounds of copper were obtained, and the bronze bells were replaced with steel ones, which, however, are proving unsatisfactory, especially in tone. The only copper roofing that remains to-day in either Germany or Austria is that on domes, as copper sheets were not removed from curved roofs because of the labor and expense involved in replacing them. Copper roofs for public buildings were very popular in Middle Europe before the war and were used so extensively that the German militarists are suspected of having availed themselves of this use as a means of quietly storing copper for the war to come. By its requisitions of copper and its alloys, it is estimated that the German Government secured 300,000,000 to 400,000,000 pounds of copper within its own territory. And added to this

immense amount were the quantities seized in Poland, Russia, Belgium, Northern France, and other territory invaded by Germany. Germany's crying need for copper can be realized when it is recalled that part of the return cargo of the transatlantic submarine, the *Deutschland,* was red metal.

Copper has always been a favorite material in man's warfare. As his earliest metal it supplanted stone cudgel and flaked arrow-heads. As a component of bronze it was a favorite material for cutting and piercing weapons long after the softer iron had become common in the ancient household. Later in history copper-containing metal was used defensively as well as offensively; shields and armor were made of brass and bronze as a foil to bronze spears and swords. Then, when hundreds of years later the age of chivalry with its metal-clad knights and chargers was in its greatest glory, brass and bronze cannons came into fashion along with gunpowder. Long-range fighting that resulted from the use of ordnance forced troops to move quickly from place to place, and, as armor hampered speedy travel, it was abandoned for this reason rather than for lack of ability to withstand gun-fire. In time, with the growth of metallurgy and mechanical skill, brass and bronze were abandoned as material for guns, but during the same transition muzzle-loaders gave way to faster firing breech-loaders. Some better way of loading than the old method of ramming home each component of the charges separately was needed, and to answer this need the cartridge of brass was devised. To-day billions of brass shells, some of them larger than the medieval brass cannons out of which

they have grown, are manufactured and used in warfare.

Archæologists have dug up much of the past of the early people on this earth, and it is interesting to note that the most impressive and best-preserved remains of ancient life relate to strife. The majority of the implements preserved are weapons, and the historical legends that were passed from mouth to mouth, from generation to generation, report warfare more clearly and with more enthusiasm than the more peaceful pursuits of every-day life. One reason for this is that the ax that was used as a weapon was also used in pursuit of an animal that could be cooked for supper. The American Indian living in the copper age used his copper-tipped spear to kill both antagonistic tribesmen and the buffalo that provided him with meat and clothing. Thus, if the hostile side of man has been given prominence in recorded history, it is partly because his fighting and his living were so intimately mixed.

It has already been explained how copper implements and weapons had a tendency to take on the same shapes as the stone ones they gradually superseded. As the next step, tin joined copper and produced harder, more durable weapons. Later, iron appeared, but it was soft and inferior to bronze until the secret of steel was learned. There was a long transition period, with ferrous weapons gradually gaining.

In the Homeric poems, bronze is the most frequently mentioned metal. The warrior of prehistoric Greece, described in these legends, wore, when in full

armor, a shield, greaves, band, belt, tunic, helmet, breastplate, and sword. As the poem tells us:

> He for Ajax framed the shield
> With hides of pampered bullocks in seven folds,
> And an eighth fold of brass,—the outside fold.

Huge shields were composed of layers of ox-hide overlaid with bronze to make them more resistant to showers of missiles. Here, as in most of the early folklore, what is translated as brass is not a mixture of copper and zinc but in reality the mixture of copper and tin that we call bronze. Protecting the legs of the Homeric warrior were legging-like greaves, and while these were generally made of hide there is reference in the poem to warriors greaved with bronze. The belt was also metal-plated, and it is generally believed that the breastplate in many cases was of bronze. It is probable that early armor was used by the fighting man that Homer describes and that they wore bronze corselets, an improved form of stiffened shirt. Moreover, copper-containing metal was used not alone for personal armor but for protection of horses and chariots and of the material for weapons, as the following passages relate:

> O warriors Ajax, leaders of the Greeks
> In brazen armor.

> His horses, and his chariot bright with brass.

> Two brazen-pointed javelins he defied
> To mortal fight the bravest of the Greeks.

And in the Bible there is also evidence of bronze armor being used (again the brass should really be translated bronze):

> And Saul clad David with his apparel, and he put a helmet of brass upon his head, and he clad him with a coat of mail.

During the early historical era of Greece and Rome, the armament of men and the form of their weapons did not differ radically from those of the legendary period that preceded these civilizations. In the latter portions of the era iron weapons were used extensively and the same metal was beginning to be used for bodily protection. For hundreds of years after Cæsar had led his legions, armor and personal combat dominated warfare. Suits of mail and plates of metal were used as late as the sixteenth century. Some armor was made of brass and bronze, but most of it, especially the elaborate suits of the later years, was fashioned of steel. About 1300, cannons appeared in Europe, and the course of warfare began to change, although it took years for firearms to replace the older methods of fighting and, as our recent dose of trench fighting shows us, hand-to-hand fighting will probably always persist.

Bronze and wrought iron vied with each other as the material for guns from early in the fourteenth century when cannons came into vogue until very recent years when modern methods of metallurgy and military tactics have made possible steel rifled guns and the subsidiary brass cartridges. Early in the

use of guns large pieces of bronze were built and used; some of these weighed as much as eighteen tons. It was only when improved design of ordnance coupled with better metal allowed the use of steel in guns of large caliber that bronze was no longer used for field-pieces and larger guns of cast-iron were superseded. Though bronze cannons have remained only in museums, the alloy from which they were most frequently made is still called gun-metal.

Peace-loving people of all ages have had a tendency to abhor the material of war. Poison gas has recently had its share of hate directed at it, and curses have been called down upon steel for making modern warfare possible. In Agricola's time (1550) people cursed metals and mining for the horrors of war. Iron had its evils, they believed, but Agricola in these words tells how they regarded copper: "Because muskets are nowadays rarely made of iron, and the large ones never, but of a certain mixture of copper and tin, they confer more maledictions on copper and tin than on iron."

Years after the last big battle has been fought, when copper is no longer used for militant purposes, when fertile fields have grown over the scene of war, when peace is at its noonday, a farmer will be reminded of war when he finds in his tractor furrow a dirt-filled brass cartridge. And when the light of the sun begins to dim and he chugs homeward he may read in everlasting bronze, the inscription:

IN MEMORIAM, FOR THOSE WHO FOUGHT AND WON.

Hardly a village nowadays lacks a military memorial, though it be only a plain bronze plaque lettered with the names of the youth of the neighborhood who have died in the service. More pretentious memorials, including a statue of a group, perhaps, are often flanked with cannons of bronze, remnants of an earlier war. Contrasting with the rust of the steel implements of later, more civilized wars, these older guns take on the beauty of bronze and vie with the memorial itself. Thousands of statues commemorating a great soldier in war, in civil strife, or in man's battle with his peaceful problems are scattered over this country. The beauty and permanence of copper has caused the overwhelming selection of bronze as the material through which veneration is expressed. In Washington the great President who saw the birth of the Union is commemorated by a tall marble shaft; facing it there is the magnificent memorial to the Presidential commander-in-chief during the struggle that kept the Union intact. A gigantic Lincoln looks kindly down from the center of the classic rectangle; his historic addresses are lettered for all time in bronze. Far above, blending harmoniously with the mural paintings, are six huge bronze beams, stayed with bronze. Eight massive bronze doors provide the entrance to the memorial, and stairways of the same metal lead to the memento rooms. Ten tons of copper in flashings and cornice promise to protect faithfully the memorial for all time, and fulfil the inscribed promise that memory of Lincoln will be enshrined there forever.

Swords may be beaten into plowshares only in a

figurative sense nowadays, but copper rotating-bands for shells are melted down and turned to peaceful uses. They and the other copper of war have fittingly been used as the metal for memorials, and the bronze cannons of the past, in addition to serving themselves, have entered the mold of the military leader who directed them. If bronze can memorialize war, it can glorify peace and good will between nations. The famous bronze "Cock of Jemappes," a shaft on Belgian soil, commemorates a French victory over a German enemy. No statue was torn down more quickly and cast into the munitions melting-pot than this reminder of defeat in 1792 when the Germans invaded Belgium during the war. Now the Gallic cock has been replaced as the symbol of Franco-Belgian friendship strengthened by alliance during the war. When the troop ships carrying the returning A. E. F. approached New York Harbor, one of the most welcome sights was the Goddess of Liberty, towering 150 feet in pure copper, the friendly gift of France to America.

The living, the rank and file as well as the officers, are honored for heroic deeds and services in war. The highest honor that the United States Government bestows upon its soldiers exclusively for acts of heroism in battle is the Distinguished Service Cross, struck in bronze. In virtually every army fighting in the World War the prized decoration for heroism in the face of the enemy was made of the same copper-containing metal. There was one notable exception—the Iron Cross. To-day few wear the khaki; the soldiers who came back are in civies. In their coat

lapels they wear the decoration awarded to all who wore the uniform, a bronze service-button. There is another age of heroes, with dwindling ranks, formed at least once a year, and they too wear a little copper badge of service. We cheer them as they pass on Memorial day; we see them as W. P. F. Ferguson has recorded in these lines in the Franklin, Pa., "News Herald":

He is bowed and old to-day
And goes limping down the way,
    With the little copper button on his breast;
And few notice as he goes,
And few think, of even those,
    Of the days when he went marching with the best.

But that little copper thing,
If you pause, will mem'ries bring
    Of what 's proudly writ upon a fadeless page,
How his valor and his truth,
In his far-off days of youth
    Wrought the mighty deeds that glorified the age.

CHAPTER XVI

BRONZE BEAUTY

Throughout the history of the world, whenever man has become master of any material, he has used it to make objects of beauty. It is not surprising, when we consider the intrinsic merits of the metals we are considering, that copper and bronze have always been favorite mediums for the production of works of art. Their history is the history of art itself.

The term Art has come to have, for us of to-day, a peculiar connotation. By an unhappy combination of circumstances we have divorced art and utility in our thoughts. According to our natures, we either praise one thing as "practical" and deride a second as "artistic," or we reverence the second as "esthetic" and damn the first as "materialistic." Ancient Greece is universally looked back to as the fount of beauty and the golden age of Art. But were you to draw the line, as we draw it to-day, between life and art when talking to a cultivated citizen of ancient Athens, he would be at a loss to understand your point of view.

Perhaps the greatest secret of the vigorous art works of early peoples was their necessity. The exploits of their gods and heroes must be kept ever fresh in the minds of the devoted worshipers, in an age when reading and writing were among the most difficult of the arts. The religious significance of early art works must be constantly borne in mind, though it does not

account for the whole story of the artistic rise and decadence of nations.

A certain instinctive love of beauty is part of the mental, or, if you will, spiritual make-up of the human race. It shows itself in many ways. One person may find a thrilling sense of satisfaction in a spectacular sunset, another in a lovely gown. One will delight in a delicately wrought bit of filigree jewelry, another in the solid mass of a modern sky-scraper. The earliest metal-worker doubtless felt as keen a sense of artistic triumph when he turned out a good copper blade as does a modern sculptor over a beautiful representation of the human form. In the main, we like things smooth, symmetrical, and colorful, relieved from monotony by interesting and unexpected detail, and nicely balanced between the severe and the fussy.

The savages who made the earliest copper and bronze implements might have used mere chunks of the metal with a rough cutting edge pounded on one side. Instead, we find that as soon as they began to master this new material they set about improving and beautifying their implements. They made them in regular shapes, they smoothed and polished them, and they began to decorate them. At first they used geometrical designs that they made up out of their heads. For a long time they advanced no further; then suddenly they seem to have become aware that they could copy the things which they saw around them. We shall refer now to no one people, for the progress of all ran along the same groove. Some went further than others before calamity or decadence overtook them, but the stages of development are

virtually the same for all. The first objects whose pictures man drew were those of animals. He took a very vital interest in them, for they furnished him food, clothing, and shelter. He watched them very closely and was able to reproduce their movements with extraordinary exactness. It is said that the position of the feet in some of the drawings of galloping animals in the caves of France have never been used since in artists' pictures but have been shown by modern slow-motion pictures to have been correctly observed and portrayed. Plants did not interest man for a very long time after he had mastered the anatomy of the animals, and his fellow-men were taken so much for granted that it did not occur to him until still later to make their likenesses. That this order was not due to superstition is indicated by the fact that children, if left to themselves, usually draw their surroundings in the same sequence.

But man's first drawings, no matter how crude they might seem to us, must have appeared very wonderful to the childlike contemporaries of the earliest artists, and the belief soon arose that considerable magic resided in the likeness of an animal or person. It was unlucky for you if any one possessed your image, but lucky for him, for he had you in his power. This superstition is believed to be the reason for those marvelous animal pictures, painted with only the naturally occurring pigments in the dark recesses of the caves of France and Spain, whose artists already possessed wonderful skill although they lived so far before the dawn of history that we know them only by these works and a few fossil bones. Artists, indeed,

they were, for they portrayed their animals in nearly every style of technique known to us at present—drawing, painting, carving, and sculpture. Of the important branches of art, only architecture was yet undiscovered.

From a picture or a statue used to charm food animals to one's traps, the transition to the worship of the representation, and then of the animal itself, is easy, even though it may have taken many forgetful generations. At the same time, as the savage's life grew less hazardous and more comfortable, he began to cease thinking of the world as an evil place. Instead of the devils with which his imagination had peopled it, he began to put gods who were friendly to him and his enterprises. His new gods were much like himself, but were still associated in his thoughts with the older creations of the tribal mind.

It is very likely that the monstrous half-animal divinities of Egypt originated in some such fashion. The halo of ancient custom hung around them, so that their worshipers saw them as symbols rather than in their hideous reality. Tribes guarded the images of their gods in the belief that their loss meant the loss of the protection of those divinities. Generals knew that the surest way to destroy the enemy's morale was to capture his gods. The tribal images were usually carved from great stones or from the trunk of a tree, but soon the custom grew up of individuals carrying small statuettes of the gods about with them. Early bronze figures of this sort have been found in excavations of Assyria and Babylonia. They are but a few inches long, and terminate in a spike which could be

stuck into the ground. How secure from harm a benighted traveler would feel, surrounded while he slept by a picket-fence of protecting divinities!

Next after depicting the likenesses of the gods, the sculptors and painters turned to representations of the rulers, who, their subjects were led to believe, were closely related to the gods themselves. Assyrian armies carried a corps of sculptors and decorators to carve the story of the king's exploits on the precipices of the mountains along their routes. The Assyrians and Babylonians excelled in relief work in metal as well, and made beautiful plaques, dishes, and even doors, but their metal experience did not include the casting of large figures. Their rivals, the Egyptians, developed metal-work to a greater extent.

Egypt was in its prime around the sixth century B. C. It was a rich country. Its fertile agricultural areas along the Nile supported cities as complex and as wonderful for their time as any modern metropolis. Its people were gay and sophisticated. In religion, always an important part of Egyptian life, they had broken away from the earlier sun worship, and followed strange cults marked by elaborate ritual. Prominent among these was the cult of the dead, which is responsible for the mummifying of bodies and the construction of elaborate tombs for the important members of society. A prominent feature of this system of rites was the erection of a stone or bronze statue of the deceased which should serve as a part-time home for his soul. A sort of reception-room was built in front of the tomb, and the statue was set up there in state and received visits and presents from

the relatives and friends of the dead man whose proxy it was. The houses of the living were thought of only as temporary dwelling-places; the tomb was the permanent home. Therefore its occupant must be made as comfortable as possible. But it was, in the nature of things, impossible to keep the tomb stocked with provisions throughout eternity, and so a very childish device of make-believe was adopted. The walls of the tomb's ante-chamber were carefully decorated with pictures of everything that the comfort of the soul might demand. Flocks of sheep were drawn there, and then the picture of a butcher killing a sheep, so that the spirit's mutton supply should always be fresh; fields of grain were pictured, and so on. It may be remarked here that no responsibility was felt by society for the souls of those who could not afford the expensive burial rites. Their poor carcasses were flung into a trench and covered with a few shovelfuls of earth, and their spirits left to fend for themselves.

This is the background for Egypt's art. Sculptors and painters were in demand by three classes of employers: the priests, to decorate the temples; the king, to extol his greatness; and those who could afford it, to provide for the future welfare of their deceased relatives. The last two offered opportunities for the development of art.

The best works date from this period or earlier. Decorated metal utensils are common, and a number of statues have been found. The figures of two scribes are well-known examples of statues made of bronze. One of them sits cross-legged on the ground, ready to take his pen in hand and write from his master's dicta-

tion. There is nothing tense in his attitude, for he is a middle-aged man, and his muscles have become flabby through years spent in a sedentary occupation, but the attitude of waiting is written all over him. His bright eyes, made of a porcelain-like enamel in black and white and fitted between his bronze lids, stare at one with a lifelike expression. The character of the subject is remarkably well portrayed. The other scribe—it only happens that both figures are of the same subject—has just surrendered his tablet to the master for inspection. With a polite smile on his lips and anxiety in his eyes, he hopes that the work will please, for he is in for a flogging if it does not. It probably will not, for this scribe is decidedly less intelligent than the other, but so pitiful is the figure that, even while we classify him as a moron, we hope the master was not too hard on him—so many centuries ago. This was Egyptian art at its greatest. Not many of its works attain this excellence.

The Egyptian metal-workers had not reached complete mastery over bronze. The face, hands, and feet were solid bronze, and cast. The rest of the body was hollow, beaten out of sheet-metal and shaped round over cores of meaner material. All the parts were then carefully matched, and joined by riveting or brazing.

The freedom of attitude and expression shown by some of the statues and a few drawings and reliefs must have resulted from work under exceptionally favorable conditions. They could not have been mortuary statues, for those were bound by propriety to a stiff posture. Still less could such natural work be done for the temples.

The temple decorations, hampered by convention, degenerated with the religion. Much earlier than the sixth century B.C., when the population was largely agricultural and the pyramids were relatively new, the religion of Egypt—or at least the chief religion—was pure sun-worship, and its priests scientific astronomers. They were the ones who painted the ceilings of the temples with azurite, the blue copper ore, to represent the heavens, and set in their places the constellations in five-pointed stars of yellow paint. The entrances of the temples faced the east, where the first rays of the rising sun could shine through arch, gateway, and door into the inner shrine and strike the jeweled breastplate of the high priest into flashing color, a symbol to the worshipers that their god was among them. As the country grew richer and wiser, many strange practices crept into the temple worship, and priest and king vied with each other for power.

In the time of Egypt's decadence, we find that the temple, instead of a simple building, had grown to an immense system of buildings, vast avenues, arch after arch and court after court, flanked with rows of massive stone sphinxes and decorated with ornate carving, sculpture, and reliefs all painted in the vivid ocher reds and copper blues that the Egyptians loved. Each succeeding ruler has added to the temple, in an effort to outshine all his predecessors. For many generations they preserved the convention of the eastern doorway, though the reason for its position had long since faded from their dogmas. But finally a king was balked in his plans by the banks of the

Nile. Doubtless there were many consultations between the powers that were, but in the end they evidently decided that the direction did not really matter very much, and the new part of the temple bends at a sharp angle to the old. The priests had so far won in the struggle for supremacy that they made the king come to the temple for instructions from the gods. The whole temple was planned at this time for the effect of mystery. Deeper and deeper grew the twilight as the king advanced through the now labyrinthine corridors. Eventually he reached the innermost sanctum, and prostrated himself before the image of the god. Every artifice was used to make this moment impressive. Then the bronze figure stirred and moved clankingly toward him, a sign of divine approbation. It was huge and hideous, and, of course, hollow and jointed. It opened its mouth and instructed the king in his duty to the gods and the proper conduct of affairs of state. We need seek no more art in Egypt. No more greatness could come from a people whose highest ideals were satisfied with this mummery.

When we turn to Greek art, we find it developing by the aid of new methods in metal-working. Although we commonly think of statues of white marble when we think of Greek art, the Greeks got their training in sculpture through the medium of bronze. Their early work, like that of the Egyptians, was made in sections, and most of the statue was beaten out of sheet metal. The technical name of this method is repoussé. The copper is laid on a block of wax, asphalt, or similar resilient material, and the design is beaten in, in in-

taglio effect; then the sheet of metal is turned around and the background is hammered down, away from the figures which now appear in relief. Greek artists became marvelously proficient in work of this kind, beating out the metal until it is very thin in the complex designs, with their delicate detail in high relief, without breaking through the metal.

But the Greeks' real statuary developed after they had passed the hammer and rivet stage, when they discovered an extremely ingenious method of casting hollow bronze statues over a core of clay, the method which is still used under the name *à cire perdue*. The figure was built up of the plastic clay and given its final outline. Then several coats of wax were applied, until the desired thickness was reached, and after the final coat the detail was put in and the statue finished. Then more clay was added until the whole figure was covered with a thick coat of it. Reinforcing-rods long enough to reach the inner core were then driven in, and the shapeless bundle was put into a furnace where the clay was baked hard and the wax melted. Holes had been left in a few places through which the wax could run out, and through them molten bronze was poured in after the baking. When the metal had had time to cool, the outer crust of clay was broken off, leaving the bronze casting in need only of a little smoothing and burnishing, and, perhaps, some inlay work of gold, silver, or jewels about the eyes, lips, and drapery. Statues made in this way possessed all the beauty and durability of the metal and at the same time gave the artist the freedom of working in a plastic material. The combination is ideal.

The early Greek sculptors preferred bronze for their statues. About the time of Phidias, marble seems to have come into favor; but that genius used bronze for his first statues, and there are many who believe that all his works were made in metal and that the marble ones that we have are only copies of lost bronze originals.

Certainly their bronze work gave to the Greeks their ability to portray motion, for their methods of modeling allowed the greatest freedom in the position of the figures without anxiety about their centers of gravity. Egypt, on the other hand, which began with stone figures, never got entirely away from the feeling of uneasiness lest the statue tip over. Many of their figures are noticeable for their perpendicular attitudes, whether sitting or standing, and those sculptors who dared put the feet a little distance apart usually left an uncut pillar at the back, giving the statue the stability of a three-point support.

The Greeks believed in having things true to life. Their marble statues were painted as to flesh and drapery, and wings and hair were often gilded. There is a legend that their metallurgists were adept at making many kinds of bronzes, and that the color of the alloy was carefully chosen with regard to the subject of the statue. A silvery metal was said to be employed in representing sea divinities, while for the sun-browned athletes the darkest bronze was used.

It is impossible here to review the technical points of superiority of Greek art, but something of the spirit which made it possible must be noted. We left Egypt with its artistic impulses and its life saddled

with mysterious cults dedicated to perpetuating the ideas of the past. Parallels are sometimes drawn between the Greek and the Egyptian polytheisms, but the Greeks were bound by no such backward-looking cults of mysticism and fear. Theirs was a joyful nature-worship, animistic, it is true, but poetically conceived. Crude as their beliefs seem to us to-day, they gave to those early people a freedom of thought never before attained. This, combined with their inherent feeling for beauty, flowered in those idealized figures of calm power and graceful strength which we still regard as among the most perfect works ever done by man, irrespective of time. When we compare them with their contemporary art in other countries we can only be amazed.

So keen was the Greek love of the beautiful that not only were their temples and their palaces beautiful but their clay bowls, copper pots and lamps, furniture, household goods of every sort were made in beautifully proportioned shapes and charmingly decorated. Of course not every potter and coppersmith was an artist of the rank of Phidias or Praxiteles, even in the golden age of Greece, but the race did seem endowed with that fine appreciation of lovely things which we call good taste. The worst of their products still have many good points. They never offend.

It is curious to see how the art movements of every people follow the same general curve. At first the artist must learn the principles of drawing and sculpture and acquire ease of manipulation of the stone, the metals, and the pigments that were at hand. Then, with the joy that comes with that power, a

THE BRIDGE

Etching on copper by Whistler, showing the delicacy of line possible in that style of work. With a minimum number of lines, the artist has given us the crowded waterfront, each figure in a characteristic attitude, the houses, the trees, the mountain in the far distance, and even the texture of the clouds. The reflections in the stream are especially interesting. Each line of an etching is scratched in a copper plate with a hard stylus and then deepened with acid to hold the ink.

Photograph by L. C. Handy

GRIEF

Augustus Saint Gaudens's masterpiece, Rock Creek Cemetery, Washington. This is one of the finest bronzes, not alone of modern art, but of all time.

spontaneous explosion of vigorous and beautiful creations appears. The decadence begins when the artists have tried their materials to their limits. Intricate technique supplants inspiration. The artists become more interested in how they do things than in what they are doing. Then criticism, comparing the results with those of earlier, more naïve workers, turns the artists back to a sophisticated imitation of earlier methods, and the quality of the result improves for a time. But in a hundred years or so this flicker has died out, and art is dead until some new impulse in the national life wakes it to new being.

Greece never reached the period of decadence. The country was but little past its prime when it fell before the Roman legionaries. Roman art, on the other hand, never had a beginning. It was not an outgrowth of the primitive Etruscan work that is found on the site of the early Roman state. Rather, the Romans, with their curious notion that they could buy brains, imported artists from Egypt and Greece, fed and clothed them, gave them the status of slaves, and ordered them to turn out so many statues a month. It is said that their systems of quantity production of art works would be a credit to manufacturers of machine parts to-day. Roman statuary found its highest use in glorifying the bloody exploits of the country's military heroes. The workmen were the best that the empire afforded—the pick of the world. The result was inevitable. Good likenesses were usually produced—only occasionally a good statue.

Statues were, however, exceedingly fashionable during the period of the Roman Empire. *Objets d'art*

were collected by amateur connoisseurs even more assiduously than during our own mid-Victorian era, and dozens, even hundreds, of statues of every quality adorned the Roman equivalent of the parlor what-not. In the ruins of one theater—not a large one, at that—were found three thousand bronze statues intended merely as incidental decoration. It is perhaps just as well that the early Christians piously set about destroying the relics of pagan Rome. Although we may have lost some fine things by it, we have assuredly been spared many things that were sins, if not against religion, certainly against art.

Bronze was always a favorite material with the Romans. Aside from its use in art works, it played an important part in religious ritual. Although iron had been known for hundreds of years it was looked down upon, and copper was considered the only proper metal for ceremonial use. The distinction was carried so far that a priest of Jupiter might shave his beard only with a bronze razor. It was decreed, too, by ancient usage that ground for a new town must be broken by a plow whose plowshare was of bronze.

When art again appears, it is under the influence of the Christian church. The Goths and the Vandals, upon embracing Christianity, imputed religious motives to their lust for destruction and stripped Rome of her landmarks of paganism. Only those statues supposed to represent the converted emperor Constantine escaped. But, even while they destroyed the older civilization, the barbarian sculptors and metalworkers were learning principles of their art. In a few centuries we find new statues, with the motive-

power of a new religion behind their creation. The Gauls of Cæsar's time were clever metal-workers. They later learned from the Romans to build of stone, and from the Byzantine school to ornament with marble and mosaics; but bronze remained a favorite medium for statues, probably gaining in favor for that use from the fact that stone statues were associated with heathen idols.

During the middle ages, painting and sculpture developed as accessories to the building of the great cathedrals. Most of the people, even the kings and nobles, were unable to read and write. The decorations of the cathedrals were intended as a course in religious history and philosophy. Their inspiration was drawn from nature. Although they were planned by the priests and made under their direction, the handling of their subjects was not conventional, and the stories of the Old and New Testaments furnished lively scenes and ample opportunity for character portrayal. Besides being used for statues, bronze was a favored material for doors, screens, reliefs, memorial tablets, and other church furniture, while copper in other forms figures largely in the rich paintings, and in the famous colored glass of the windows.

Cast objects at this period were made by the modern process instead of the *à cire perdue,* or "lost wax" method of the ancients. The newer process has the advantage that accidents caused by unfortunate circumstances or a careless workman at the bronze founder's do not destroy the artist's original creation. The modern artist, after building a frame of iron bars and wooden scaffolding, covers it with clay which he can

shape at will, and then makes a cast of the whole in plaster and from that a plaster model. Upon this model are placed the final finishing touches, before it is sent to the metal caster. The metal caster makes his mold from the plaster model. Of course, the molds made around the figure are in hundreds of separate small pieces, so that they can be removed without danger of breaking any part. When the molds are ready the molten metal is poured through places where some of these pieces have been withdrawn. It fills the space between the mold and the inner core, for bronze statues are never solid. The metal is too precious to waste on any place which will not show.

All through the middle ages, art was progressing. Materials were mastered, technique was standardized, composition was developed. The Renaissance was only the fulfilment of all that had been learned before. But with the Renaissance came a change in the mission of art. It soon began to appear outside the church. Wealthy families could afford things formerly possessed only by the church. Their desire for beautiful paintings and statues gave a new impetus to art. But the greatest new influence in the world was the printing-press. Men no longer had to study the pictures in the cathedrals if they were curious about those who had lived before them. They began to go to books for such things. And, for the first time in the world, art was without a definite mission. It was set off by itself. It might assist other departments of learning, but it was not bound by them. It was set suddenly and completely free for the mere pursuit of beauty. The mechanical multiplication of the written word

took away art's obligation of story-telling. The Reformation threw art out of the church. The acrimonious years that followed so fettered the minds of the religious disputants that the joy necessary to creative work was quite dead. Art in the churches soon degenerated to the distressing monotony which marks it to-day.

We are accustomed to think of the Renaissance as a distant event. But if the love of art and science was reborn in the fifteenth and sixteenth centuries, it is still in a period of vigorous growth. Hindered from time to time by social upheavals and foreign wars, the intellect of the race goes on conquering the materials of which the world is made and the laws by which they can be put to the use of man. Is not this the first step toward their free use for the satisfaction of man's inherent need of beautiful surroundings? If the process seems slow, we must remember that even the flowering of the Greek genius required many hundred years of preparation, and how much more complex a world modern science has opened up for us to conquer!

When the archæologist of the year 4422 A. D. looks back at the art of our era his adverse criticisms may be: "It was a period of transition which, although producing many excellent things, followed rather too closely older masterpieces of painting and sculpture, whose technique had already reached perfection," and "the art works seem to have been grouped together in special buildings whose use, other than as mere museums, is unknown to us. This practice, if our assumptions concerning it are correct, must have deprived great numbers of people of the opportunity

to become acquainted with the works of their great artists. Lacking the training which they might have received through constant association with beautiful surroundings, it is doubtful whether the general level of taste among the less fortunate classes was very high."

The Egyptians built elaborate tombs; the Greeks made temples and statues to idealize their heroes; the Romans erected triumphal arches; the people of the middle ages built cathedrals. What will be our characteristic form of expression in art? It is as yet too early to know definitely. Art of the future may well have as its object the beautifying of our daily lives. The old order of magnificent public buildings surrounded by mean and filthy huts is beginning to seem incongruous to the world to-day. But, whatever its form, we may be sure that the art of to-morrow will be machine-made.

The fact that this sounds paradoxical is the result of an artistic tragedy—nothing less. When the mechanical age first dawned, Art, who had always had to rely on her two hands, forgot the potter's wheel on which she made her lovely vases and the looms on which she wove her beautiful fabrics, and cried out that she never could learn to understand that horrid machinery and that she would have nothing whatever to do with it. She tried to hide her unwillingness to learn something new with the statement that things made in great numbers all alike are incapable of beauty, but the facts are quite otherwise; for an archæologist can often place the origin of a bowl or a bronze celt quite accurately within a few years and a hundred miles, be-

cause its shape and decoration were the invariable rule at that place and time, and, at that place and time, such a shape and decoration represented a very high form of artistic feeling. No, the plain facts are that artists were afraid of the new fields. It was so much easier to go on painting and modeling as hundreds of others had done before, regardless of the fact that all the important principles of those methods had already been worked out. And so the manufacture of our furniture and clothing and building-trim and statues was largely left for a time to factory foremen who used a great new power without vision and visited some atrocities of taste upon a helpless market. But the worst of their products have found their way to the junk-piles, and we can now see evidence of the tardy appearance of the artist in the plant designing-rooms. In the future we may expect to see the artist take his place beside the engineer, the sanitarian, and the scientist as one of those who make the world a better place to live in. We may be sure that the beauty of copper and bronze will always make them favorites whether for utilitarian bowls and pans or for the portrayal of the slender grace and rugged strength of human figures, just as they have always been.

If the metals are fused more carefully and blended more exactly by the aid of electricity instead of charcoal; if the molten product is carried by automatic cars to the molds, instead of by sweating human bodies; if it is run into a thousand molds at a time instead of one; if the beauty of the finished object can be enjoyed by the humble, instead of the rich art patron alone—who will be the loser, if the mold be designed by another Phidias?

CHAPTER XVII

COPPER'S FUTURE

Old as the very hills themselves, man's first metallic aide would seem to be in its old age. Yet in reality copper is still in the adolescence of its second youth. Before it lies the world eager for its help. It has been a leader in the mechanical revolution that the world has been experiencing, and it will continue to carry many of the burdens of the new era.

The science of electricity has just begun to yield results of considerable magnitude. The vulgar mind has only begun to appreciate the possibilities of sending power along a copper wire as water is sent through a pipe. Every progressive country on earth is looking forward to getting on an electrical basis. While water plunges over falls wastefully, the far-seeing man does not like to use coal, which only the sunshine of countless ages could replace. He will demand that hydraulic power be harnessed and driven through copper to his home and factory. Projects actually planned will require many millions of pounds of copper in the next few years.

Though communication had the aid of electricity and copper before the electric dynamo and motor created and used copper-carried electric power, tomorrow will see new means of human intercourse. The telegraph allowed written messages to travel with

electrical speed; the telephone throws the human voice across continents. Within a few years pictures and photographs will be sent from place to place with telegraphic speed; the next step will be actually to transmit the scenes themselves, and we shall see through copper stretched many hundreds of miles.

Brass and bronze will continue to perform their service for many years, but to these copper alloys there will be added new partnerships that may be far superior for many uses. And it is probable that these new combinations will be designed before being built. With the X-ray spectrometer the metallurgist is learning the secrets of metallic combinations. By laborious experiments he is mapping on alloy constitution diagrams the properties of various alloys when their ingredients vary in material and percentage. Soon it is expected that the rules of alloying and the resulting properties will be discovered with such precision that the metallurgist will be able to compete with the chemist and produce new, valuable, and synthetic alloys, having predetermined properties, just as the chemist makes new drugs, chemicals, and dyes.

It is possible that the days when another Butte or Katanga can be discovered are passing, yet the prospector must be with us always in order that the world may continue to have an ample supply of red metal. But the prospector will be of the new era; he must not be visualized as a picturesque character, with his "outfit" and a few burros. More likely he will be found in a research laboratory. New mines in the future will be found but infrequently; new ways to mine known deposits and concentrate and smelt lean ore will

be eagerly sought and found. The prospector of to-morrow will play a game of hide-and-seek with Nature, but he will work in the mine, reduction plant, or refinery and not in totally unexplored country.

In this world there is only a certain, limited amount of copper. All the people who come after us to live on this earth will have that quantity and no more. In fairness to our descendants we must use copper and all other natural resources intelligently and carefully.

Yet we have a very good reason for using all the copper we actually need and for doing so with a clear conscience. Unlike most metals, copper is not a rapidly wasting asset. Copper in many cases loses but little of itself even during long service. There is, to be sure, some wastage; and in some cases, as when its salts are used for insecticides, none of the copper content can be reclaimed. Yet, years after its first mining, most copper can be remelted and utilized again in some other form. Millions of miles of copper wire now in use in power, telephone, and telegraph systems will add just as much comfort, pleasure, and efficiency to future generations as to the present.

To restrain ourselves unduly in our present use of copper for fear of future shortage would also be discounting the continued ability of man to conquer the vital problems that will confront him. In the distant future it is possible that copper will not be so essential as it now is, because of the perfection of new aids to civilization.

When copper's low depreciation is contrasted with

iron's expensive rusting, the picture is striking. Every year an amount of iron, said to equal one fourth of the annual production, reverts to its most contented form, rust. While the blast-furnace has been producing four pounds of new iron, one pound has rusted away. In a generation, if all iron production stopped, there would be little left to show that there ever was an iron age. Corrosion also means loss of coal, because for every pound of iron produced about four pounds of this valuable basic fuel are required. This phase of the situation is more serious than the loss of the iron, since our coal supplies are more severely limited than our iron ore. Nearly twenty million tons of iron revert to red rust during each year. Iron is spent when it is used and its scrap value is often virtually nothing even if it misses its usual fate of rusting.

To use copper, however, is to invest it. Since 1800 there have been produced a little more than 27,000,000 tons of copper. Much of this will continue in use for many years longer; a large part of it will be re-used. Suppose that only half of this quantity is reclaimable at ten cents a pound scrap value; it represents an investment of about $3,035,000,000, which is increased at the rate of about $125,000,000 a year. No other common metal can show such a balance-sheet.

Some day in the future there will be an event comparable in importance to the completion of the Atlantic cable or the driving of the last spike of a transcontinental railroad. It may be the throwing of many superpower electric systems into one continental unit

or the completion of a gigantic world net of electrical communication. How fittingly symbolic it would be if the switch on that occasion were fabricated from a copper ax, a relic of the days of the youth of civilization!

READING REFERENCES ON COPPER

Much information not contained in the preceding pages will be desired by those who wish detailed knowledge of certain phases of the history, nature, manufacture, and use of copper. Further data on copper are to be found in more technical volumes. Often the subject that is dismissed with only a chapter or even a paragraph of this book will occupy the whole of some technical work. The object of this book is to introduce copper to the reader rather than to expose all the details of its character; it is hoped that the reader will be interested enough to search out the more technical volumes and absorb what they contain about red metal.

CHAPTER I

For a realization of the way in which man arose through the ages and the part that the various factors in civilization played in his evolution, no better book can be read than "The Outline of History" by H. G. Wells (Macmillan). The small amount of detailed information on the use of copper and copper alloys in early time is scattered in several places. "Man and Metals," by Walter Hough, curator of anthropology of the United States National Museum (Proceedings

of the National Academy of Sciences, Vol. II, March, 1916), is an interesting analysis of the connection between man's early use of metals and fire. Dr. Hough in the Proceedings of the United States National Museum, Vol. LX, has also described a synoptic series of objects in the National Museum illustrating the history of inventions. In the development of the knife, ax, adz, hammer, saw, drill, piercing and stabbing weappons, cutting and thrusting weapons, and harpoon the material is stone, bone or wood, copper or bronze, and then iron and steel in virtually all cases. A summary of the use of copper and its alloys in early times, with analyses of ancient copper and alloys, is contained in the presidential address of Professor William Gowland before the Institute of Metals, London, 1912, published in the "Journal of the Institute of Metals," Vol. VII. The state of metallurgical knowledge in the sixteenth century has been preserved for us in the first comprehensive text on mining and metals, "De Re Metallica," by Georgius Agricola. From the first Latin edition of 1556, Herbert Clark Hoover and Lou Henry Hoover have made an English translation whose notes amply explain the text and summarize what is known of metallurgy up to Agricola's time. This work was published for Mr. and Mrs. Hoover by the "Mining Magazine," London, 1912. Several of its interesting woodcuts are reproduced in the text of this book. Much information on the use of copper by the American Indians and the aborigines of Central and South America can be found in the reports of archæological work on the past history of America. Bul-

letin 30 of the Bureau of American Ethnology, edited by Dr. J. Walter Fewkes of the Smithsonian Institution, contains a brief summary of the Indians' use of copper, with a bibliography. "Bronze in South America Before the Arrival of the Europeans," by Adrien de Mortillet, in the Smithsonian report for 1907, reports analyses of pre-Columbian metals, as does "Prehistoric Bronze in South America," by Charles W. Mead, in Anthropological Papers of the American Museum of Natural History, Vol. XII, Part II, 1915. An account of the early use of copper and bronze is contained in "L'humanité prehistorique," by Jacques de Morgan, published in Paris. "Prehistoric Times," by Sir John Lubbock (Lord Avebury), published by J. A. Hill & Co., contains information on the ancient use of copper and bronze. A guide to the antiquities of the bronze age in the British Museum was published by the museum in 1904, and collections of copper and bronze implements of early times can be found in virtually all the large museums. A series of articles, "An Illustrated History of Mining and Metallurgy," by H. H. Manchester, were published in the "Engineering and Mining Journal-Press" in the autumn of 1922 and have been reprinted in pamphlet form. They contain interesting information on the four periods: the Egyptian period, that of the Greeks and Romans, the Middle Ages in Europe, and in sixteenth-century America. An article by the same author in the same journal for May 19, 1923 (Vol. 115, No. 20) gives an interesting account of mining in Old Japan.

CHAPTER II

Accounts of the mineralogy and geology of copper may be found in all of the ordinary texts on geology and mineralogy. A semi-technical review of the geology of copper may be found in such a book as "Economic Geology," by Heinrich Ries (John Wiley & Sons), or "General Economic Geology (A Text Book)," by William Harvey Emmons (McGraw-Hill Book Co.). More limited treatment can be found in "Engineering Geology," by Heinrich Ries and Thomas L. Watson. "The Data of Geochemistry," by F. W. Clarke, Bulletin 695, U. S. Geological Survey, is a comprehensive work on the crust of the earth and includes a chapter on copper. For methods of identifying and testing the ores of copper and the minerals in whose composition copper plays a part, a book on mineralogy like "Elements of Mineralogy, Crystallography, and Blowpipe Analysis," by Alfred J. Moses and Charles Lathrop Parsons (D. Van Nostrand Co.), should be consulted. The Bureau of Mines has also issued a pamphlet on the "Ores of Copper, Lead, Gold and Silver," by Charles H. Fulton, as Technical Paper 143 (Government Printing Office, Washington). A standard work on the genesis of the parts of earth's crust that are rich enough to be called ore is "Mineral Deposits," by Waldemar Lindgren (McGraw-Hill Book Co.). This presents in one volume on coördinated summary and interpretation of the various theories and investigations of mineral deposits. Detailed descriptions of copper minerals and deposits may be found in the many geological reports that have been

made on those portions of the world that contain copper. Experts of the United States Geological Survey have made many of these, and the reports of this bureau contain much of the public information on the mineralogy of copper.

CHAPTER III

From a geographical and quantitative standpoint, as well as geologically, technical information on copper is scattered in many books and reports. In "The Copper Mines of the World," by Walter Harvey Weed (McGraw-Hill Book Co.), the copper-producing centers are treated from a geological and mining point of view. This book provides a handbook on the copper resources of the world. A more recent digest of statistical and technical information relative to the production, consumption, and value of copper has been issued in 1922 by the Imperial Mineral Resources Bureau of the British Government. This publication entitled, "The Mineral Industry of the British Empire and Foreign Countries: Copper," covers particularly the war period for 1913 to 1919. In addition to its text, it contains a valuable bibliography of the technical literature on copper since 1913, which includes references on occurrence, distribution, and mining, listed geographically, and also those on ore dressing, metallurgy, alloys, and uses. A summary of copper's place in political and commercial affairs is contained in a chapter on copper by F. W. Paine in "Political

and Commercial Geology and the World's Mineral Resources,'' edited by J. E. Spurr (McGraw-Hill Book Co.). A similar summary, though not so technical, written during the war instead of after, is the chapter by B. S. Butler in ''The Strategy of Minerals,'' edited by George Otis Smith (D. Appleton and Company). The distribution, production, and consumption of copper in all parts of the world and the United States are shown graphically in the valuable World Atlas of Commercial Geology, Part I, ''Distribution of Mineral Production,'' that is published by the United States Geological Survey. Information on the history and geology of the different mining centers must be sought in the periodical literature, Geological Survey reports, and literature issued by the various copper companies. ''The Copper Mines of Lake Superior,'' by T. A. Rickard (''Engineering and Mining Journal''), is a book covering the Michigan region. A review of Alaskan copper history and prospects is found in ''The Future of Alaskan Mining and the Alaskan Mining Industry in 1919,'' by Alfred H. Brooks and G. C. Martin, Bulletin 714A of the United States Geological Survey. Other Geological Survey reports, such as Professional Paper 115, ''The Copper Deposits of Ray and Miami, Arizona,'' by Frederick Leslie Ransome, will be interesting to those who may wish to know more about a certain region. A monograph of the British Imperial Institute on ''Copper Ores'' by Robert Allen which was published in 1923 (John Murray, London) gives a summary of copper production, largely from a British point of view; but its data on foreign deposits will prove of interest.

CHAPTER IV

Old as mining is, the literature on winning metals from the earth is constantly growing. Information on new copper mining methods and new mines is contained in such periodicals as the "Engineering and Mining Journal-Press" or the proceedings of societies such as the American Institute of Mining and Metallurgical Engineers. Herbert Hoover, mining engineer and Secretary of Commerce, is the author of a standard work on "Principles of Mining" (McGraw-Hill Book Co.). The various copper companies also have issued bulletins on mining, and the publications of the United States Bureau of Mines contain similar information. For reference, a handbook like "Mining Engineers' Handbook," by Robert Peele (John Wiley & Sons), is useful. In "The Cost of Mining," by J. R. Finlay (McGraw-Hill Book Co.), data are given on the financial side of mining.

CHAPTER V

The experiences that copper has on its journey from mine to metal are the subjects of many books on metallurgy. Most extensive of these is "Metallurgy of Copper," by H. O. Hofman (McGraw-Hill Book Co.), which gives copious references to detailed reports and studies on all the technical phases of copper's reclamation. A more recent book, but one that treats the subject less fully, is "The Metallurgy of Common Metals," by Leonard S. Austin (John Wiley & Sons),

which also includes sections on general metallurgy and common metals. Hofman's general book on metallurgy might also be used for reference. A connected outline of the processes employed in the production of copper is contained in a small English book, "Copper from the Ore to the Metal," by Hugh K. Picard (Isaac Pitman & Sons, London). Other books that may be consulted on the metallurgy of copper in its various phases are: "The Principles of Copper Smelting," by E. D. Peters (McGraw-Hill Book Co.); "The Hydrometallurgy of Copper," by William E. Greenwalt (McGraw-Hill Book Co.); "Copper Refining," by Lawrence Addicks (McGraw-Hill Book Co.). The Anaconda Copper Mining Company has issued a pamphlet, "Copper from Mine to Finished Product," which explains the processes at their various reduction and refining plants. "The Smelting of Copper Ores in the Electric Furnace," by Dorsey A. Lyon and Robert M. Keeney, is Bulletin 81 of the United States Bureau of Mines, and other of the publications and current investigations of the Bureau of Mines touch on the metallurgy of copper. The magazines, "Chemical and Metallurgical Engineering" (New York), "Engineering and Mining Journal-Press" (New York), "The Metal Industry" (New York), "The Brass World" (New York), "Mining Magazine" (London), and "Mining Journal" (London), and the transactions of the American Institute of Mining and Metallurgical Engineers, the Institution of Mining and Metallurgy, the British Institute of Metals and the American Electro-Chemical Society contain accounts of current advances in metallurgy. The chapter on

"Copper" in the "Mineral Resources of the United States, Part I, Metals," issued annually by the United States Geological Survey, contains a summary of the production and consumption of copper year by year. "The Mines Handbook," an enlargement of the "Copper Handbook," by Walter Harvey Weed, is an annual volume that reviews the copper industry from a more commercial standpoint. Its most important feature is a list of mining companies. Statistics on production of copper month by month are contained in the Survey of Current Business issued by the Department of Commerce. An analysis of the cost of copper is contained in "Costs of American Copper Production, 1909–1920, Inclusive," by H. A. C. Jenison in the "Engineering and Mining Journal," Vol. CXIII, No. 11, March 18, 1922. A valuable summary of "The Marketing of Copper" is published by Edward H. Robie in the "Engineering and Mining Journal-Press" for April 23, 1923. Those interested in copper share statistics may refer to a sheet compiled by E. N. Skinner, New York mining engineer, which annually tabulates data on various copper companies from a financial standpoint. Other useful statistical books are "The Mineral Industry." (McGraw-Hill Book Co.) and "The Yearbook of the American Bureau of Metal Statistics."

CHAPTER VI

The cold, solid figures that represent the physical and chemical properties of the metal can be found

in the "Smithsonian Physical Tables, Seventh Revised Edition," published by the Smithsonian Institution. The mining, metallurgical, chemical, and mechanical engineering handbooks may also be consulted for such data. For further information on the close study of metals, the two volumes on "Metallography" by Samuel L. Hoyt (McGraw-Hill Book Co.) are recommended. This work treats of alloys as well as pure metals. The Bureau of Standards has also issued a number of valuable publications on copper. Bureau of Standards Circular 72, "Copper," covers metallography, both chemical and physical properties, and technology, and includes an extensive bibliography. Bureau of Standards Circular 113, "Structure and Related Properties of Metals," gives a general and illuminating review of the methods for revealing the structure of metals and the application of microscopy of metals. "Metallographic Etching Reagents for Copper" is the subject of Bureau of Standards Scientific Paper 399, by Henry S. Rawdon and Marjorie G. Lorentz. Chemical and electrolytic methods of analyzing copper and its ores are adequately covered in "The Analysis of Copper," by George L. Heath (McGraw-Hill Book Co.). The relatively new methods of spectographic analysis are treated in Bureau of Standards Scientific Paper 444, "Practical Spectrographic Analysis," by W. F. Meggers. A short paper by W. H. Bassett and C. H. Davis, "Spectrum Analysis in an Industrial Laboratory," issued with "Mining and Metallurgy," February, 1922, as a part of the Transactions of the American Institute of Mining and Metallurgical Engineers, is also interesting. For discus-

sions of some of the more recent ideas about the states and conditions of metals, recent magazine articles should be consulted. Jerome Alexander has a series of four articles on "Colloidal State in Metals and Alloys," in "Chemical and Metallurgical Engineering," Vol. XXVI, January 11, January 18, January 25, and February 1, 1922. Other articles in the same magazine are: "Grain Growth and Recrystallization in Metals," a series of three articles by Zay Jeffries and R. S. Archer, February 22, March 1, and March 8, 1922; "The Amorphous Metal Hypothesis," by the same authors, October 12, 1921; and "A Discussion of the Slip Interference Theory of Hardening," by Paul D. Merica, May 10, 1922. For an account of the methods used in X-ray examination of crystals the reader should consult "Studies of Crystal Structure with X-rays," by Edgar C. Bain, in "Chemical and Metallurgical Engineering" for October 5, 1921. A synopsis of Dr. Walter Rosenhain's work on "Hardness and Hardening" may be found in "Chemical and Metallurgical Engineering" for May 21, 1923. Specifications covering the tests to be made and the requirements to be filled by copper and its alloys when used in various ways are given in the book of standards issued triennially by the American Society for Testing Materials.

CHAPTER VII

For a more detailed look inside the copper atom, the reader is advised to follow John Mills in his work,

"Within the Atom" (D. Van Nostrand Co.). Though this is somewhat technical it is an adequate presentation of our knowledge of the sub-molecular world. The original presentation of Irving Langmuir's hypotheses on "The Arrangement of Electrons in Atoms and Molecules" is contained in his article under that title in the "Journal of the American Chemical Society," June, 1919, Vol. XLI, and, though this is not very easy reading, it is not too technical for the layman. A very interesting account of how electrons and alpha particles are seen and photographed is contained in Sir Ernest Rutherford's article, "Constitution of Matter," in the Smithsonian Institution Annual Report for 1915. "The New Knowledge," by Robert Kennedy Duncan (Harper & Brothers), is a little old now, but it is good as far as it goes. "The Structure of the Atom," by Professor N. Bohr, published as a supplement to "Nature" (London), July 7, 1923, explains the newest interpretation of the chemist's atom as a solar system, as it is seen by the physicist.

CHAPTER VIII

The partnerships in which copper becomes involved are so intimately related to its inside story that the references given in connection with Chapter VI should also be considered applicable to this chapter. For information on alloys of copper and aluminum, Bureau of Standards Circular No. 76, "Aluminum and its Light Alloys," should be consulted, and copper-nickel alloys are explained in Bureau of Standards Circular

No. 100, "Nickel." The list of alloys referred to in Chapter VIII was compiled by Professor William Campbell of Columbia University for Committee B-2 of the American Society for Testing Materials and appears on pages 213–242 of their proceedings for 1922, Part 1. A practical volume on alloys prepared by an expert on alloying and casting metals is "Metals and Their Alloys," by Charles Vickers (Henry Carey Baird & Co.).

CHAPTER IX

Much of the best information on the manufacture of copper and its alloys is contained in advertising literature issued by the copper and brass companies. The Anaconda booklet referred to previously contains a description of copper wire rolling, and "Seven Centuries of Brass Making," a booklet issued by the Bridgeport Brass Company, Bridgeport, Connecticut, gives a brief history of the ancient art of brass making as well as the more modern processes. Circular No. 52 of the Bureau of Standards tells of the "Regulation of Electrotyping Solutions," and the Transactions of the Faraday Society, Vol. XVI, Part III, July 1, 1921, contains a review of papers on electro-deposition and electroplating. Reference may also be made to "Foundry Practice," by R. H. Palmer (John Wiley & Sons), and "Electro-Deposition of Metals," by George Langbein and William T. Brannt (McGraw-Hill Book Co.). Those who wish to try their own hand at making copper products should consult "Cop-

per Work: A Text Book,'' by A. F. Rose (The Davis Press, Worcester, Massachusetts).

CHAPTER X

So fundamental is copper to the existence of electricity that complete reference to books telling of their coöperation would be impossible. Data on copper wire and the electrical properties of copper may be found in electrical engineering handbooks and tables. The current literature, such as the periodicals, ''Electrical World'' and ''Electric Railway Journal,'' necessarily contain many references to the electrical uses of copper. ''Telephone Service,'' Bureau of Standards Circular No. 112, explains in much detail the way in which telephones and their complex systems form a part of our every-day life. Another Bureau of Standards publication, Letter-Circular 68, ''The Common Uses of Electricity,'' gives an idea of the universal use of electricity in the household. Of the many books on radio that have been published in the last few years, ''Letters of a Radio-Engineer to His Son,'' by John Mills (Harcourt, Brace, and Company), will probably best explain to the determined reader why and how radio apparatus, made largely of copper, does its work. Lightning-rods are discussed in a chapter of ''Agricultural Meteorology,'' by J. Warren Smith (Macmillan).

CHAPTERS XI, XII, XIII

The uses to which copper has been placed are so

common and varied that references are seldom isolated and are largely scattered throughout the literature. One booklet, "Consumption of Copper and its Varied Uses," by H. D. Hawkes (published by Cameron, Michel and Co., New York), contains a large amount of data, much of it statistical in nature, on the various tasks to which copper has been put by man. The Copper and Brass Research Association, an organization of producers and fabricators of copper and copper alloys, located at 25 Broadway, New York City, issues a periodical bulletin devoted to the uses of copper. The advertising literature of the various copper and brass companies also contain much data on the use of red metal and its alloys. Publications of the director of the mint tell more about the making of our copper money.

CHAPTER XIV

Like information on the use of copper, data on its compounds and their uses are scattered throughout the vast mass of literature describing the processes in which compounds of copper take part. Chemical texts, dictionaries, or handbooks may be consulted for detailed information concerning copper's compounds.

CHAPTER XV

War utilizes all the industries of peace and forces the creation of many additional copper-consuming ac-

tivities. How war material was produced in America during the World War is told in "America's Munitions, 1917–18," the report of Benedict Crowell, Assistant Secretary of War and director of munitions (Government Printing Office, Washington). Incidentally this volume tells of the modern war use of copper.

CHAPTER XVI

A vivid description of the life of ancient Egypt is contained in "Manual of Egyptian Archæology," by Sir G. Maspero, translated by Agnes S. Johns. "The Story of Art throughout the Ages," by S. Reinach, translated by Florence Simmonds, is an illustrated, condensed history of sculpture and painting. Its account of the art works of Babylonian, Hittite, and other early peoples is especially complete. Covering the latter, better known periods in the history of art there is a great variety of books of history and criticism.

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